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# A NEW SPECIES OF TYPHLOPLANA (RHABDOCOELE TURBELLARIA) AND SOME ADDITIONAL DATA CONCERNING MESOSTOMUM VIVIPARUM (SILLIMAN) FROM NORTHERN INDIA

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## 1. Introduction.

The earliest record of investigation of Typhloplana (Rhabdocoela) is of more than one hundred and forty years old. Muller (1774) gave an account of *Rhyncho- mesostoma rostratum*, Abildgard (1789) described *Typhloplana viridata* and since then allied freshwater Turbellarians have been carefully worked out by a large number of distinguished workers. In America the first description of the common planarian was given by Leidy[23] (1848). The Indian species of Rhabdocoele Turbellarians, however, have received little attention and no description of any species of Typhloplana from India seems to exist. This communication provides an account of a new species of the genus Typhloplana *T. vitellata sp. n.* found in freshwater lakes and ponds near the river Ganges in Allahabad and records a few observations on the structure of *Mesostomum viviparum* from pools near the same river in Benares. These Turbellarians show certain peculiarities in structure and habits of life which make them particularly interesting.

## 2. Methods and Technique.

Samples of surface water from different parts of the pond were taken in jugs with a quantity of algae and weeds and brought to the laboratory for examination. Sometimes only the algae and weeds were taken up and placed in a jar with a small amount of water. The bottom-mud was also scraped up, but this contained mostly aquatic oligochaetes. Glass basins 11″ broad and 7″ high served for aquaria in which the flow of water was maintained by means of water taps. The

collections were made periodically from August to April, for two years, from pools of water artificially cut off from main stream of the Ganges by embankments. One pool near Bund Road in which the water remained comparatively less agitated by cattle provided the most sure and plentiful material. In this pond Spirogyra, Nostoc, and other algae were quite profuse and hence regular oxygen supply was assured — a condition very favourable for the Rhabdocoele Turbellaria, which though found throughout the winter months were particularly abundant in March and April.

Isolated specimens were kept alive for several days in a watch glass, some of them lived for nine to twelve days during the month of December at room temperature. But in April when the days are fairly warm they die soon. The water in the watch glass, however, was not artificially aerated, but was changed every morning and evening.

The worms are so delicate that even the pressure of a cover glass is sufficient to crush them. They are, however, studied in the living condition by putting spirogyra filaments under the cover glass. In order to check the movements of the worm drops of 10% chloretone were dropped underneath the cover glass gently and with great care as otherwise, the integument is liable to get ruptured.

For permanent preparation specimens were narcotised by a fairly large dose of 10% chloretone which was added little by little until they expanded. Warm saturated solution of corrosive sublimate in physiological salt solution and hot Zenker's fluid without acetic were used for fixation. Acetic acid as far as possible should not be used in the fixative as it readily brings about a rupture of the integument. The anaesthetic was not used in the case of worms fixed in Zenker's solution. The specimens from Benares were fixed in Flemming's fluid without acetic and Champy's solution. For toto preparations materials fixed in corrosive sublimate solution and stained with Borax carmine gave good results. The sections were stained with Iron Haematoxylin or Borax carmine and Picro Indigo carmine.


## 3. HABITS OF LIFE.

Some observations were made on the habits of life of the worms and their reaction to external stimulii and poisons. In a jug full of pond water and algae, allowed to stand overnight, it was seen that almost all the individuals had left their hiding places and come to lie near the surface, and in this condition they can be easily collected either by means of a pipette or by draining out the surface water of the jug in another glass basin.

It appears that they react negatively to the stimulus of light avoiding the sunlight as much as possible and habitually living in dark shady places among large clumps of aquatic plants and masses of algae.

The reaction displayed by the worms to anaesthetising agents and poisons is interesting. Although they are very delicate in structure, they appear to offer a remarkable resistance to anaesthetics and poisons. A comparatively large dose (added very gently drop by drop) is necessary to narcotise them. The following (table 1) shows the relative reaction of four different poisons on the flatworm:—

*Table 1*

| No of worms in 10 c. c. of pure water. | Chloral hydrate 10 per cent. | Chloretone 10 per cent. | Alcohol 90 per cent. | Tobacco extract (strong). |
|---|---|---|---|---|
| 5 | 1·5 c.c. | 1 c.c. | 1·5 c.c. | 3 c.c. |
| 8 | 1·7 c.c. | 1·5 c.c. | 2·1 c.c. | 4·2 c.c. |
| 10 | 1·8 c.c. | 1·8 c.c. | 2·5 c.c. | 5 c.c. |
| 12 | 2 c.c. | 2·1 c.c. | 2·6 c.c. | 5·5 c.c. |

### 4. MORPHOLOGY OF TYPHLOPLANA VITELLATA N. Sp.

*T. vitellata* are gregarious, occurring in large numbers particularly in the months of March and April. The colour is white and appears to remain so constantly, while in most Rhabdocoeles it is dull and varying. The worms are extremely delicate and unable to withstand even the light pressure of a cover glass. The size of living specimens (Fig. 1) varies 1 mm. to 1·8 mm. in length and from 0·2 mm to 0·5 mm in breadth. Apparently all individuals observed were sexually mature. Fixed specimens (Fig. 2) measured 0·8 mm. to 1 mm. in length and 0·1 mm. to 0·3 mm. in breadth. The variation in size depended also upon the amount of food swallowed and the degree of development of the reproductive organs.

The surface of the body is covered with a coat of cilia by the movements of which the worm glides gracefully on the slide. The cilia also enable the animal to propel its body through entanglements of algae and weeds in the aquarium. The body is elongated and cylindrical but not very flat. The anterior end is bluntly pointed and can be drawn in, to a slight extent, on contraction (Fig. 2, PRB). A pair of eye spots is situated on the dorsal side a little behind the anterior extremity. The posterior one-fourth of the body narrows back rapidly to a pointed tip. The mouth is situated on the ventral side at about one-fourth body length from the anterior end. The genital aperture (Fig. 3 GP) lies immediately behind the pharynx. The eggs are brown and visible through the transparent skin.

*Epithelium.* The integument is composed of a single layer of columnar epithelial cells ciliated on the outside. The cilia are extremely fine and visible

under the high power only. The cells contain small spindle-shaped rhabdites (Fig. 7, RBD) lying either singly or in pairs, which are scattered all over and not localised to any particular part of the body. Underlying the columnar epithelium lies a very thin basement membrane with which is connected a thin layer of muscle fibres. The average thickness of the integument is 6$\mu$.

*The Muscular System.* The musculature is feebly developed in the body-wall. It consists of fine fibres running in all directions to form a sort of mesh-work just beneath the basement membrane. It is better developed towards the anterior end where a bundle of threadlike strands of muscles connects the extremity with the parts behind (Figs. 3 & 5, PRBM). The fibres in this bundle are long and arranged in antero-posterior or oblique direction helping the animal to retract or protrude its anterior end, which is the most sensitive part of the body.

The pharynx is thick and muscular and worked by muscle fibres connecting it with the ventral body wall. The intrinsic muscles of the pharynx are thick, stout bands running on the outer and inner edges of the bulb. There are also a few concentric sphincter muscle bands on the outer margin of the bulb rendering the pharynx an efficient suctorial organ.

The cirrus is muscular and lies in the neighbourhood of the pharyngeal bulb (Fig. 4, CIR). There is a distinct atrium; the atrial pore is provided with a sphincter muscle. Bands of muscle fibres connect the cirrus to the body wall evidently to control its protrusion and retraction.

*Parenchyma.* The parenchyma or mesenchyma is composed of irregular vacuolated cells (Figs. 3, 5, 6, PAR) of very variable forms (spherical, ovoidal or angular) lying in the interstices between the organs. The parenchyma cells are subject to compression and strain. When the intestine is choked with food the cells appear to be squeezed out of existence. On the other hand when the digestive cavity is empty the lumen of the intestine is almost obliterated and the whole body seems to be made up of parenchyma alone. The cells also conduct food and oxygen to different parts of the body through the intermediation of the fluid in the vacuoles which act as a sort of water vascular system

*Digestive System.* The mouth is situated on the ventral side, in the anterior third of the body, and leads into a powerful muscular pharynx (Fig. 4, PHR) which bears rosette-shaped spines at the internal end. The pharynx opens into a simple sac-like intestine which extends antero-posteriorly. The wall of the intestine is not very clearly distinguishable when there is no food in the intestine as it is pressed considerably by the parenchyma and surrounding organs. Unlike many Rhabdocoela, which generally live on dead organs, *Typhloplana vitellata* seems to be carnivorous feeding upon small living aquatic oligochaetes. It is an aggressive species, which was found on many occasions to attack in numbers the Naids and other aquatic oligochaetes breaking their body into pieces with the powerful pharynx.

*Nervous System.* The nervous system is diffuse and not sharply marked off into nerve centres. The nerve cells and fibres are almost undifferentiated from the general tissues of the body. There is hardly any indication of nerve swellings to form a definite cerebral ganglion, at the anterior end. The nerve fibres are, however, much more concentrated between the two eye spots than elsewhere in the body to form the brain. The nerve fibres are also distributed over the general surface of the skin.

*Sense Organs.* The two eyes are the only sensory organs (Fig. 1) which lie anteriorly, on each side of the median line, dorsal to the brain beneath the epithelium. Each is a simple aggregation of dark, coarse pigment granules, surrounded by cells which are supplied directly with nerve fibres from the brain.

*Reproductive System.* The reproductive organs consist of two tubular testes, one ovary, four lobes of vitelline glands and a cirrus (Fig. 4, CIR). The genital opening is single and lies ventrally in the middle line close to the pharynx. The testes are elongated structures situated ventral to the intestine. Their ducts are short and lead to the cirrus. The cirrus is an ovoidal muscular organ about one-third the diameter of the pharynx measuring $40\mu - 50\mu$ in greatest diameter.

The ovary is a small spherical body lying close to the pharynx. During the spring when a large number of isolated eggs are found in the body, it becomes greatly shrunken. The eggs, 20—30 in number nearly fill the whole of the interior of the body—some crowded towards the head, others lying in the middle and the posterior regions. Most of the eggs have a very thick shell of dark brown colour. Those are probably winter eggs. Others which are probably newly formed have a thin transparent shell. The size of the eggs varies from $50\mu - 130\mu$ in diameter. The vitelline glands of a characteristic shape are composed of four groups of compact follicles, which are situated ventral to the intestine. During the sexual period they grow to a large size but towards the close of the spring they shrink very much to make room for the fully grown eggs. The eggs are shed to the exterior either through the genital pore or frequently through a temporary rupture, in the body wall, at any place. Although a large number of specimens were examined regeneration was not observed in any case. Occasionally I met with an individual filled with ova becoming inactive and breaking its dorsal body-wall to discharge the eggs. The rupture did not heal and the worm consequently perished.

Attempts were made to study the stages in the development of the worm but all the extruded eggs kept for the purpose disintegrated before long.

*Excretory System.* The excretory tubules can be seen faintly in living specimens. There are two longitudinal tubules on either side, running along the margin, throughout the whole length of the body. A little in front of the pharynx, the two lateral tubules give out two tiny branches which approach each other forming a loop ventrally and open to the exterior by a median canal near the edge of the pharynx.

The genus *Typhloplana*, as it now stands, comprises only two species :— *T. marinus* Oersted and *T. viridata* Abildgard of which only the latter is a freshwater form. The following (table 2) giving characteristic features of *T. viridata* and *T. vitellata* indicates the marked differences between these species. *T. marinus* being a marine species is not included in the table for comparison.

*Table 2*

| Characters. | *T. viridata*. Abild., 1789. | *T. vitellata*. N. Sp. |
|---|---|---|
| Habitat ... ... | Freshwater ... ... | Freshwater. |
| Length ... ... | 0·5—1 mm. ... ... | 1·0—1·8 mm. |
| Anterior end ... | The anterior end is contractile, the amount of contraction is much less. | The anterior end is very much contractile. |
| Colour ... ... | The presence of zoochlorellae imparts the colour which varies from pale gray-green to brilliant green. | The colour is cream-white. No symbiotic algae observable. |
| Rhabdites ... | Rhabdites are small 8-9µ cylindrical rods with round blunt ends, lie in the parenchyma just beneath the epithelium. | Rhabdites are much smaller 3-4µ spindle-shaped, pointed at both ends, lie in the epithelium. |
| Genital pore ... | Posterior to the pharynx guarded by a broad band of circular muscles. | Posterior to the pharynx-rosette, near the edge, guarded by a sphincter muscle. |
| Testes ... ... | Two large solid lobes ventral to the intestine | Two lobes of testes ventral to the intestine. |
| Cirrus ... ... | Cirrus large, nearly as large as the pharynx. | Cirrus small, about ⅓ the size of the pharynx. |
| Ovary ... ... | Single ... ... ... | Single. Situated near the Pharynx. |
| Vitelline glands ... | Two lobes ... ... ... | Four lobes. |
| Eggs ... ... | 90—100 ... ... | 80µ |

The two species are distinguished from each other here in the following respects : —

    1. Colouration.
    2. Size of the body.
    3. Shape of the anterior end.
    4. Size and form of the vitelline glands and cirrus.
    5. Dimensions of the rhabdites.

## 5. Mesostoma (*TYPHLOPLANA*) viviparum Silliman

Silliman[18] described this species from lakes of North America under the name of *Mesostoma viviparum.* Luther[25] and Von Graff[15] considered it as identical with the European species, *Typhloplana viviparum.*

The writer had an opportunity of examining some specimens of *Mesostoma (Typhloplana) viviparum* collected by Dr. H. R. Mehra, in 1924 from a pond, near Benares (North India). The specimens resembled in many respects the European and American types.

The worms in the fixed condition measured 2·0—2·5 mm. in length and 1·0 mm. in breadth. The head and the tail are not pointed but they are somewhat blunt. The rhabdites (Fig. 8, RBD) are spindle-shaped. The intestine appears only as a chink in the parenchyma (Fig. 9, S. I.), no distinct layer of epithelium surrounding the intestine is visible in any of the sections cut by me. The pharynx is a spherical rosette-shaped structure which is seen fairly well developed even in the embryos contained within the uterus.

The reproductive organs (Fig. 10) are complicated and difficult to make out. The ovaries and the testes are not clearly visible as the worms were probably not collected in the breeding season. The vetelline glands consist of two elongated follicles lying laterally to the intestine. The most interesting feature, as already observed by previous workers, is the viviparous habit. The young ones are developed in a special brood pouch which is an outgrowth of the uterus lying on the dorsal side of the intestine (Fig. 9, EMB). There are usually two to four embryos occupying the uterus.

## 6. Classification.

The first systematic classification of the Rhabdocoele Turbellarians was given by Ehrenberg[11] (1831—36). He established the genus *Typhloplana* in 1831 and five years later in 1836 created the family Mesostomidae to include a large number of genera—*Eumesostomum, Mesostomum, Typhloplana* etc. In 1852 Leuckart[24] published his monograph on *Mesostomum ehrenbergi* and retained the family name Mesostomidae. Von Graff[15] in his memorable work "Monographie der Turbellarian Rhabdocoelida" published in 1882, maintained eight species of *Typhloplana* six of which he regarded synonymous as follows:—

> *Mesostomum sulphurium* De Mann = *Typhloplana sulphurium* O. Schmidt.
> *Monotus lineatus* Diesing (Alloiocoela) = *Typhloplana flustrae* Johnston.
> *Mesostoma gracialis* Mihi = *Typhloplana gracialis* Schmarda.
> *Mesostoma herudo* O. Schmidt = *Typhloplana herudo* Diesing.
> *Mesostoma griseum* Mihi = *Typhloplana flava* Ehrenberg.
> *Derostoma flava* Graff (Vorticidae) = *Typhloplana variabilis* Oersted.

Subsequently, however, in 1905, he himself split up the family Mesostomidae by removing the genera *Typhloplana* and *Eumesostomum* into a separate family called

*Typhloplanidae.* He retained *T. viridata* and *T. marinus* in the genus *Typhloplana* and relegated the six abovementioned species to other genera. This system of classification remained in practice until Poche[29] (1925) propounded his elaborate scheme in which the order Rhabdocoela is broken up into twenty-one families.

A chart giving the diagnostic characters of the families and genera of the freshwater Rhabdocoela is appended.

## 7. SUMMARY

The anatomy of a new Rhabdocoele Turbellarian (*Typhloplana vitellata*) is described and its differences with other species of the genus are pointed out.

The bionomics of the new species is given and its food, mode of locomotion, response to light and reaction to narcotics are considered.

Some additional data regarding *Mesostoma viviparum* Silliman are provided based on the study of the Indian specimens.

A brief history of the genus *Typhloplana* is furnished and a scheme for the diagnosis of the family and genera of the order Rhabdocoela is provided in the appendix.

# APPENDIX

## Diagnostic Key to the Families, and Genera of the Order Rhabdocoela.*

GROUP (A)—*Pharynx: simple.*

Reproductive organs simple. Female organ consists of ovary only; no uterus, no female copulatory apparatus, etc. Asexual reproduction is found to exist.

Order Rhabdocoela Ehrenberg, 1831.
Intestine—A simple blind tube.
Pharynx.—Simple, cask-shaped or rosette-shaped, or long cylindrical bulbous.
Connective tissue of the body-cavity poorly developed. The parenchyma consists of a few strands of connective tissue with large spaces filled with fluid.

GROUP (B)—*Pharynx: rosette-shaped, or cask-shaped.*

Situated perpendicular to the ventral surface or slightly inclined.

GROUP (C)—*Pharynx: long cylindrical bulbous.*

Without statocyst or preoral circular groove, with ciliated pits.
Genus Catenula.

Ciliated pits well developed without proboscis.
Genus Stenostomum. O. Schm.

Family Catenulidae Graff, 1905.
Protonephridium with *one* principal branch; median dorsal in position.

Ciliated pits shallow, clubshaped probosis is present.
Genus Rhynchoscolex.

(A) *Pharynx: simple, etc.*

Pharynx opens into anterior end of the intestine which has short diverticula.
Genus Macrostomum. E.V.B.

Family Microstomidae Hallez, 1894
Protonephridium with *two* lateral branches.

Mouth on the ventral surface, intestine extends dorsally and anteriorly beyond the pharynx. Testes and ovary either paired or unpaired. Two sexual apertures ventrally disposed, male posterior to the famale. With or without eyes.
Genus Microstomum. O. Schm.

* For details of classification, the works of Graff[15] Poche[29] Steinmann and Bresslau[40] and several others mentioned in the Bibliography may be consulted.

F. 2.

Family Grafillidae, Graff, 1908. Pharynx pyriform or with a barrel-like structure. Reproductive organs :—T h e female genitalia consists of either a paired or unpaired germ-vitellaria or with a pair of germaria and vitellaria. Parasitic in habit.

With a unpaired germ-vitellaria.
Genus Archivortex silvestris Reis. With paired germ-vitellaria-or germaria and vitellaria.
Genus Vejdovskya Graff—marine.
Genus Anoplodium Schneider. Parasitic in Gastropoda (mollusc)
Genus Fecampia Giard. in Decapod crustacia.
Genus Grafilla Jher. in Gastropoda.
Genus Syndesmis Silliman. in Echinoids.

Family Dalyellidae, Graff 1905. Pharynx cask-shaped parallel to the ventral surface or slightly inclined with t h e e n d directed forward with only one genital pore.

Sexual pore anteriorly situated, Yolk glands network or much branched Genus Dalyellia Flemming 1882.
Genus Phaenocora Ehrenberg, 1836.

With a separate pocket for chitinous portion of the male copulatory organ.
Genus Jensenia Silliman, 1885.

*(B) Pharynx: r o s e t t e-shaped or cask-shaped, etc.*

Family Gyratricidae Ehrenberg, 1831. Pharynx rosette, situated a little anterior to the middle. Reproductive organs :—Vitelline glands large and ovary small. Two genital pores instead of one Proboscis bearing Rhabdocoeles.

Ovary lying in the centre, testes dorsal to the intestine.
Genus Gyratrix. Ehrb.
Genus Schizorhynchus. Hallez
Genus Polycestus.

Family Mesostomidae Ehrenberg, 1836. Pharynx rosette, situated in the middle of the body. Vitellaria follicular. Genital pore behind the mouth.

With one genital pore Genus Mesostomum M. Ehrenbergii Focke, 1836.
M. angulare Higle. With two genital pores, male anterior to female
Genus Byrsophlebs Jensen.
Genus Proxenetes Jensen.

Tribe Protoplanellini Reisinger, 1923. Genital pore in the posterior third of the body. Vitellaria situated ventral to the testes and separated from the opening of the excretory duct.
Genera Protoplanella, Olisthanellinella, etc., etc.
Reisinger, 1923 (30) (see Zool. Anz.)

Family Typhloplanidae   Graff 1905.

Pharynx rosette-shaped standing perpendicularly to the ventral surface.

Tribe Typhloplanini  Reis 1923.

Genital pore in anterior two-third of the body. Vitellaria ventral to the testes. Testes not very far separated from the excretory pore.

Genera :—

Macrophysalophora Reis, 1923.
Adenoplea . . . . . . [see Reisinger (30) Rhynchomesostoma Muller.
Anterior end of the body a retractile proboscis, body fluid red or yellowish-red, intestine contains orange oil drops. Strongylostoma Silliman, 1885. Without proboscis and atrial copulatory apparatus.   With separate receptaculum seminis.
Genus Typhloplana.
   T.  Viridata Abild.
   T.  Vitellata n. sp.
Pharynx just anterior to the centre. Sexual pore close behind the pharynx. Without receptaculum seminis. Zoochlorellæ imparts green colour to the body in T. viridata.  Tapering at both ends. Anterior end slightly retractile.

*(B) Pharynx rosette-shaped or cask-shaped, etc., (contd).*

Reproductive organs :—
Genital pore behind the mouths Ovary single, Testes paired.
Excretory tubes with two main branches which may have either one or two openings on the ventral surface or may lead to the mouth or sexual pore.
Ciliated pits may or may not be present.
Rhabdites play important part in classification.

Family Prorhynchidae Diesing
Without accessory female copulatory organ.  Male pore opens in common with the pharynx. Ovary single germvitellarium. Pharynx long.

Genus Prorhynchus. M. Schm.

*(C) Pharynx long cylindrical bulbous.*

Family Solenopharyngidae Carus.
With accessory female copulatory organs.
Pharynx cylindrical bulb-like.

Genus Solenopharynx. V. Gr.

Family A c a n t h o p h a r yngidae Pharynx bulbosus (Reis).

Genus Acanthopharynx Reis.

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## EXPLANATION OF FIGURES

: (*Typhloplana vitellata*, Figs. 1-7. *Mesostomum viviparum*, Figs. 8-10. All figures
have been drawn under camera lucida.)

Fig. 1.—Dorsal and ventral aspects of living specimens. The pharynx rosette is seen on
the ventral side. Here and there are eggs with orange-red shell wall. The eye
spots are situated dorsally at the anterior end.

Fig. 2.—Five mounted specimens under low power. The eggs are grouped at the centre.
The anterior tip is retracted in all the specimens.

Fig. 3.—Entire mount showing general anatomy. The vitellaria are four-lobed. The ovary
is single.

Fig. 4.—Diagrammatic representation from life showing genital opening and pharynx.

Fig. 5.—A median longitudinal section showing internal anatomy.

Fig. 6.—Transverse section through the retracted anterior end.

Fig. 7.—Transverse section of the integument showing epithelium with rhabdites.

Fig. 8.—Transverse section of the integument showing epithelium with rhabdite (M. viviparum.)

Fig. 9.—A median longitudinal section showing embryos in uterus.

Fig. 10.—Part of the above highly magnified showing genital opening and pharynx.

# LETTERING

CIR.—Cirrus.

EMB.—Embryo.

EG.—Egg with thick brown shell.

EP.—Integumentary epithelium.

GER.—Germarium.

GP.—Genital pore.

PAR.—Parenchyma.

PHE.—Pharynx of the embryo.

PHR.—Pharynx rosette

I RB.—Proboscis. (Retractile anterior end.)

PRBM.—Proboscis muscle.

RBD.—Rhabdite.

SI.—Intestinal space.

SV. —Seminal vesicle.

T.—Testes.

VIT.—Vitelline gland.
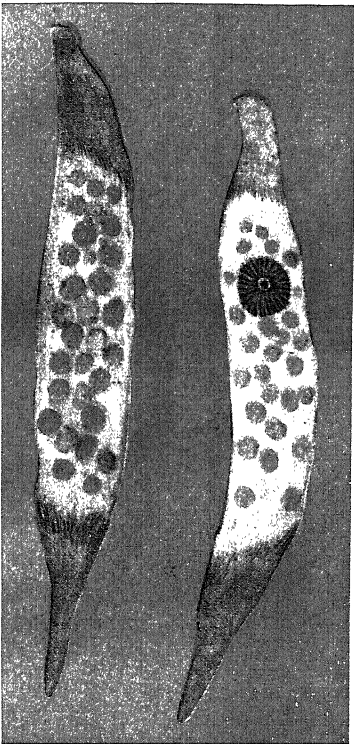
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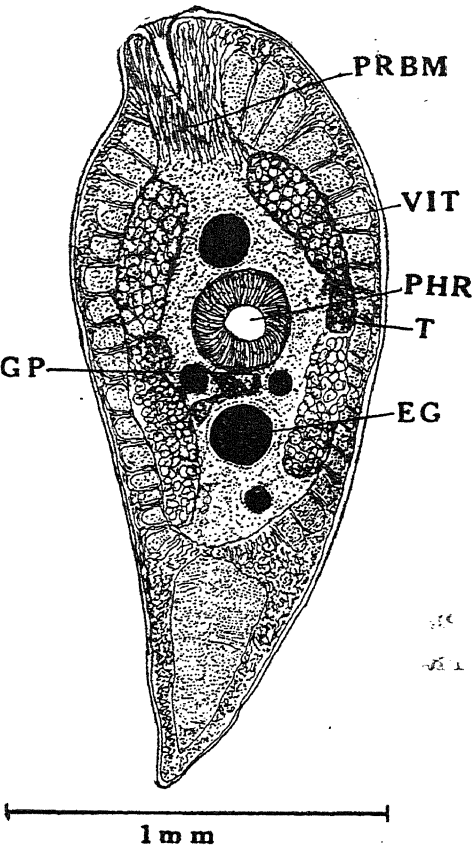


Fig. 3



Fig. 2



Fig. 4

Fig. 5



Fig. 6



Fig. 7

PAR

EMB

PHE

EMB

SI

PHR

CIR

1 mm

Fig. 9

GER

SV

PHR

CIR

$\frac{1}{10}$ m m
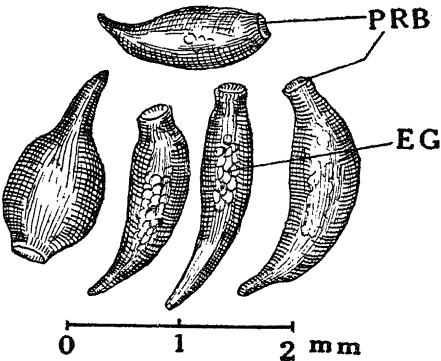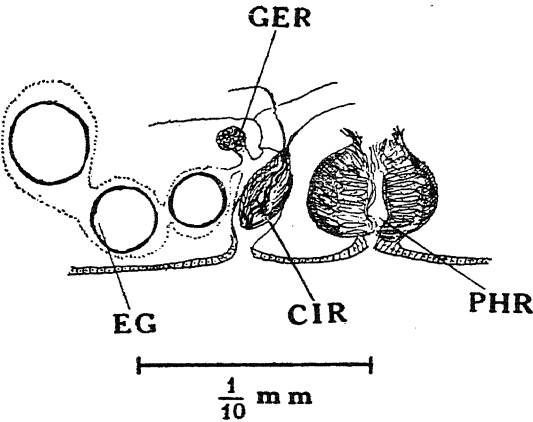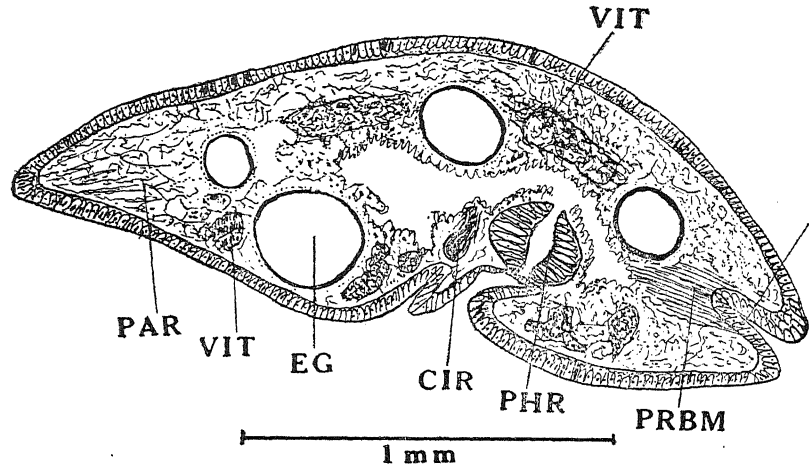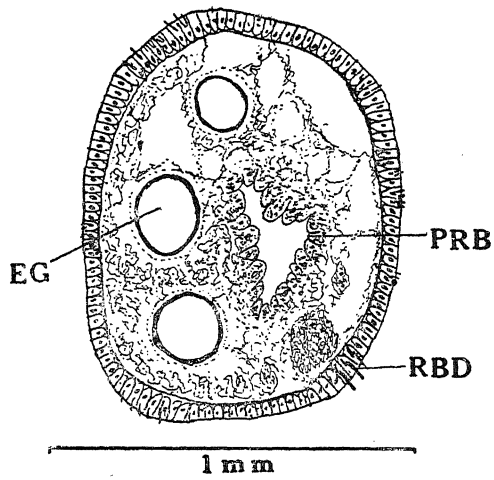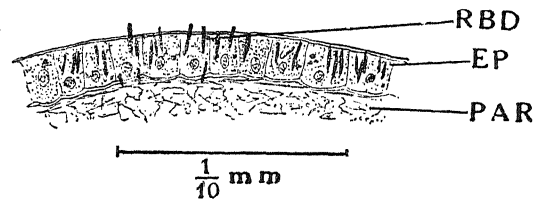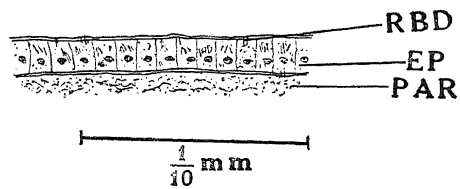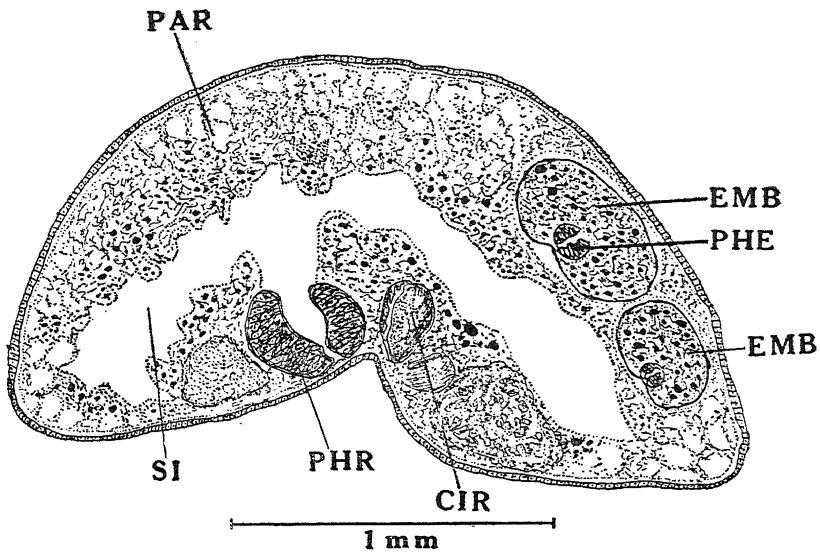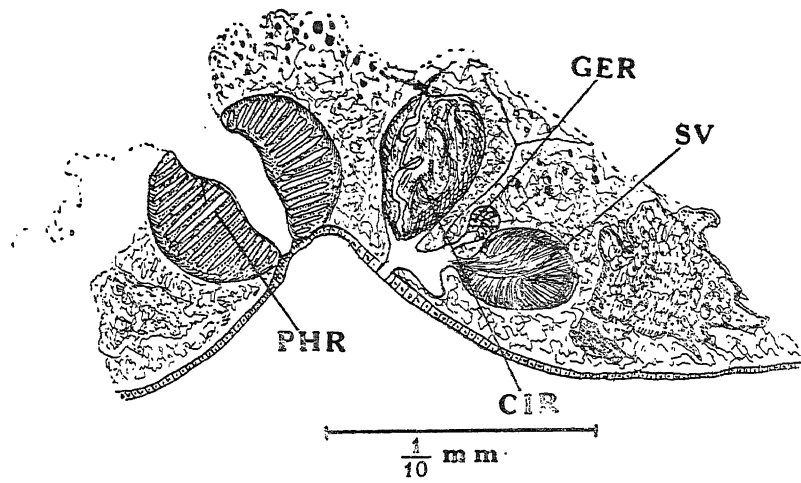
Fig. 10

# ON THE EXISTENCE OF A METRIC AND THE INVERSE VARIATIONAL PROBLEM

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1. An extension of Riemannian Geometry begins with the postulation of existence of $n^3$ functions of position $\Gamma^i_{jk}$ which are transformed by the point transformation $(x \leftarrow \rightarrow x')$ in the following manner :

(1.1)
$$\Gamma^i_{jk} = \Gamma^r_{mn} \frac{\partial x'^i}{\partial x^r} \frac{\partial x^m}{\partial x'} \frac{\partial x^n}{\partial x^k} + \frac{\partial x'^i}{\partial x^r} \frac{\partial^2 x^r}{\partial x'^j \, \partial x'^k}$$

We here adopt the following notation :—

(a) The "dummy index" occurring both as subscript and superscript indicates summation over all values.

$$A_r \, u^r = A_1 \, u^1 + A_2 \, u^2 + \ldots\ldots\ldots + A_n \, u^n$$

(b) But when underlined, the summation is not to take place ; also, indices on the same level with a bar over them are to be summed :

$$A_{\underline{r}} \, u^{\underline{r}} = \text{the } r\text{th term in } A_c \, u^r$$

$$A_{\bar{r}} \, u_{\bar{r}} = A_1 \, u_1 + A_2 u_2 + .. A_n \, u_n .$$

(c) A comma followed by an additional subscript denotes partial differentiation. A semicolon in place of the comma will indicate that the variable of differentiation is $\dot{x}^n$ in place of $x^k$ .

$$\frac{\partial A::}{\partial x^k} = A::, k \qquad\qquad \frac{\partial A::}{\partial \dot{x}^k} = A:: ; k$$

(d) A vertical bar in place of the comma or semicolon will be used for covariant differentiation, the indices being those of a tensor.

2. Our equations (1. 1) allow us to perform a good many of the operations possible in Riemannian manifolds, without any hypothesis as to the existence of distance, or of a groundform. The usual formulæ for covariant differentiation holds. We have a parallelism, and thence the equation of "paths," i.e., curves having autoparallel tangents :

(2.1)
$$\ddot{x}^i + \Gamma^i_{jk} \, \dot{x}^j \, \dot{x}^k = 0$$

$$\dot{x}^i + \Gamma^i_{jk} \, \dot{x}^j \, \dot{x}^k = {}_a\dot{x}^i . \qquad\qquad \text{[Schouten]}$$

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One operates with the Γ's precisely as with Christoffel symbols of the second kind in a Riemannian space, and thus obtains a mixed curvature tensor

$$(2.2) \qquad R^{h}_{ijk} = \Gamma^{h}_{ik,\,j} - \Gamma^{h}_{ij,\,k} + \Gamma^{m}_{ik}\,\Gamma^{h}_{mj} - \Gamma^{m}_{ji}\,\Gamma^{n}_{mk}$$

Even more general results as the theorem of Fermi can be extended. The principal difficulty arises in discussing the problems of mathematical physics. There is no way of defining the magnitude of vectors, no way in which an index can be raised or lowered, i.e., covariant and contravariant tensors associated. Laplace's equation

$$(2.3) \qquad \triangle\ V = \text{div. grad. } V = 0$$

cannot be expressed, as the divergence of a covariant vector cannot be defined here. Similarly, the famous gravitational equations of the older Einsteinian theory

$$R_{ij} - \tfrac{1}{2}\,Rg_{ij} = \lambda\,T_{ij}$$

lack a basis of deduction, the $g_{ij}$ having no meaning. The restricted case

$$R^{h}_{ijh} = R_{ij} = 0$$

can still be treated, though on a purely formal basis.

Thus, it is not immediately profitable to investigate space-time, and the possibilities of a physical world based on a set of Γ's that differ but little from their Euclidean or Galilean values, which are all null. A first step must therefore investigate the possibilities of measuring " distance," of founding the affine manifold on a Riemannian. If we assume or define the paths of our geometry to be the actual paths of material particles, or of disturbances in space-time, the geodesics of older speech, an added contact is established with material reality.

We take the path equations (2.1) as our starting point. Symmetry of the Γ's

$$(2.6) \qquad \Gamma^{i}_{jk} = \Gamma^{i}_{kj}$$

may be assumed from the algebraic symmetry of (2.1) without loss of generality. To discuss the existence of a Riemannian groundform,

$$(2.7) \qquad \left(\frac{ds}{dt}\right)^{2} = g_{ij}\,\dot{x}^{i}\,\dot{x}^{j}$$

is equivalent to discussing the solutions of

$$(2.8) \qquad g_{i}\ g_{ij/k} = 0$$

$$g_{ij,k} = g_{ih}\,\Gamma^{h}_{jk} + g_{hj}\,\Gamma^{h}_{jk}$$

The above system of partial differential equation being the familiar system of Koenig, is completely integrable if the compatibility conditions

$$(2.9) \qquad g_{ih}\,R^{h}_{jkl} + g_{jh}\,R^{h}_{ikl} = 0$$

are fulfilled. If identically, we have $R^h_{ijk} = 0$ and the totally uninteresting case of a flat or Galilean space. If not, further conditions can be derived (Eisenhart).

$$(2.10) \qquad g_{ih} R^h_{jkl/m} + g_{jh} R^h_{ikl/m} = 0$$

by covariant differentiation of (2.9). The process must lead to the sets of solutions, or to the absence of any. The method has been brought to a greater degree of elegance by Graustein, for the case of Einstein spaces.

The contracted curvature is the only fundamental covariant tensor of rank two that enters into our theory. If it does not vanish identically, it is natural to build another space using this as a ground-tensor.

$$(2.11) \qquad \left(\frac{d\sigma}{dt}\right)^2 = R_{ij} \dot{x}^i \dot{x}^j$$

In this associated space, the operations that we call physical are possible, if $R = |R_{ij}|$ does not vanish. A co-tensor of rank two can, by the process of finding the normalized co-factors of its square array, be associated with a contravariant tensor of the same rank. The further operations proceed as in any Riemannian space. An Einstein space is one for which the first associate is identically null, or conformal to the original space. One may find a second and further associate spaces, by a continuation of the same process. The difficulty again lies here in the meaninglessness of conformality for affine connections.

I, therefore, propose to approach the problem from another point of view, and to see first the types of metric that can be deduced from a given set of paths. In equations (2.8), the following various properties are expected of the solutions :

(a) $g_{ij} = g_{ji}$. If this does not follow from the equations, we can at any rate replace $g_{ij}$ in the groundform by $\frac{1}{2}(g_{ij} + g_{jt})$. It is seen that in general $g_{ij} + g_{ji} \neq 0$.

(b) $g_{ij}$ must be a covariant tensor of rank two.

$$g'_{ij} = g_{mn} \frac{\partial x^m}{\partial x'^i} \frac{\partial x^n}{\partial x'^j} \quad (x \leftarrow \rightarrow x')$$

If the equations are taken as invariant under a point transformation, and we assume

$$g'_{ij} = \phi^{mn}_{ij} \, g_{mn}$$

a set of relations will be obtained involving $x$, the $g$'s, the $\Gamma$'s, and $\phi^{\alpha\beta}_{\partial\delta}$ as well as $x^i, x'^k$. If it be further demanded that the $\phi$'s be purely functions of the transformation, $(x \leftarrow \rightarrow x')$, not explicitly dependent on the $g$'s or the $\Gamma$'s, we have a set of equations satisfied by

$$\phi^{m\,n}_{i\,j} = \frac{\partial x^m}{\partial x'^j} \frac{\partial x^n}{\partial x'^j}$$

It does not transpire that these are the only solutions possible, but I do not intend to develop this possible generalization of the tensor here.

(c)  $g=|g_{ij}|\neq 0$. This is usually another condition added to the equations. If however (2.8) has a solution, it follows that

$$\frac{\partial}{\partial x^k}\log g=\Gamma^r_{r\,h}$$

The value of $g$ being other than null initially, it will not vanish.

(d)  Continuity, differentiability, and other analytic properties of the $g$'s depend on the corresponding properties of the $\Gamma$'s. Uniqueness of the solutions does not in general hold, but the various groundforms must give spaces in geodesic correspondence.

(e)  The distance $s$, represented by

$$\int_{p_0}^{p} ds,$$

must be stationary over the paths given by (2.1). This is usually written as $\delta \int \sqrt{g_{ij}\dot{x}^i\,\dot{x}^j}\,dt$ with the extra condition $g_{ij}\dot{x}^i\,\dot{x}^j =$ const. along the extremals. We replace it by

$$\delta\int g_{ij}\dot{x}^i\,\dot{x}^j\,dt=0$$

It is intuitively obvious that this will do as well. We can consider the geodesics as the actual trajectories of a particle of unit mass sliding on a smooth hypersurface of the given groundform under a zero potential. The least action formula is precisely the one that we have adopted, and the auxiliary condition is merely the conservation of energy. The Eulerian equations become

$$z\frac{d}{dt}\left(g_{ij}\dot{x}^j\right) - g_{k,\,ij}\,\dot{x}^k\,\dot{x}^j = 0.$$

These reduce to $g_{ij}\left[\ddot{x}^i + \Gamma^i_{jk}\,\dot{x}^j\,\dot{x}^k\right] =0$ if and only if (2.8) is fulfilled and if $g$ is not zero, these will be identical with (2.1).

It is the main purpose of this paper to follow the last condition more closely, and to investigate its full significance.

3.  Given a single differential equation of the second order

(3.1)            $\ddot{x} + a\,(x,\,\dot{x},\,t)=0$

It is asked whether there exist any functions of $x,\,\dot{x},\,t$ such that

(3.2)            $\delta\int f\,(x,\,\dot{x},\,t\,)dt=0$

represents by its extremals the curves that are solutions of (3.1). The Eulerian equation is

(3.3)            $\frac{d}{dt}f\dot{x} - f_x = 0$

$$\ddot{x}\,f_{\dot{x}\dot{x}}+ \dot{x}\,f_{x\dot{x}} +f_{\dot{x}t}- f_x = 0$$

If then, such an $f$ exists, the equation (3.3) must be reducible to (3.1) with almost a factor of proportionality, $\xi(x, \dot{x}, t) \neq 0$

$$\xi [\ddot{x} + a] = \frac{d}{dt} f_{\dot{x}} - f_x$$

This gives directly,

(3.4) $\quad \xi = f_{\dot{x}\dot{x}}, \quad \xi a = \dot{x} f_{\dot{x}x} + f_{\dot{x}t} - f_x,$

$$- a f_{\dot{x}\dot{x}} + \dot{x} f_{\dot{x}x} + f_{\dot{x}t} - f_x = 0$$

And we may state

Theorem 1.— *The equation $\ddot{x} = a(x,\dot{x},t)$ gives the extremals of $\delta \int f dt = 0$ if and only if $f$ is a solution of*

$$a \frac{\partial^2 f}{\partial \dot{x}^2} + \dot{x} \frac{\partial^2 f}{\partial \dot{x} \partial x} + \frac{\partial^2 f}{\partial \dot{x} \partial t} - \frac{\partial f}{\partial x} = 0$$

such that $\qquad \dfrac{\partial^2 f}{\partial \dot{x}^2} \neq 0$

Since the partial differential equation always has a solution, we could have stated that every second order differential equation can be deduced from a variational principle. The solution is not unique, as the addition of any perfect differential leaves the Euler equations unchanged. As a corollary, we have,

*The linear differential equation*

$$\ddot{x} + \dot{x} P(t) + x Q = 0$$

*is equivalent to*

$$\delta \int e^{\int P dt} \frac{1}{a} \left[ \dot{x}^2 + 2 x \dot{x} P - x^2 \left( Q - \frac{dP}{dt} - P^2 \right) \right] dt = 0$$

This could have been derived from inspection after the equation is put in the normal form and the integrand transformed back again. It must be kept in mind that $cf + \dfrac{dv(x)}{dt}$ gives the same equation as $f$.

The same derivation will now be attempted for systems of second order differential equations.

4. We start with the system

(4.1) $\qquad \ddot{x}^i + a^i(x, \dot{x}, t) = 0 \qquad i = 1, \ldots n$

which is to be deduced from

(4.2) $\qquad \delta \int f(x^i, \dot{x}^k, t) \, dt = 0.$

Here the single factor of proportionality will be replaced by $\rho^{ij}(x, \dot{x}, t)$ since both (4.1) and the expanded Euler equations

(4.3) $\qquad \ddot{x}^j f_{\dot{x}^i \dot{x}^j} + \dot{x}^j f_{\dot{x}^i x^j} + f_{\dot{x}^i t} - f_{x^i} \qquad = 0$

are linear in $\dot{x}^i$. This leads to

$$\rho_{ij} = f_{;i;j} \qquad \rho_{ij}a^j = \dot{x}^j f_{;i;j} + \frac{\partial}{\partial t} f_{;i} - f_{,i}$$

$$(4.4) \qquad a^i f_{;i;j} - \dot{x}^i f_{;j,i} - \frac{\partial}{\partial t} f_{;j} + f_{,j} = 0 \qquad \left| f_{;i;j} \right| \neq 0.$$

We may then state the theorem

Theorem 2. *The system of equations (4.1) is deducible from a variational principle if and only if there exists a solution of the partial system*

$$a^i \frac{\partial^2 f}{\partial \dot{x}^i \partial \dot{x}^j} - \dot{x}^i \frac{\partial^2 f}{\partial x^i \partial \dot{x}^j} - \frac{\partial^2 f}{\partial \dot{x}^j \partial t} + \frac{\partial f}{\partial x^j} = 0$$

*such that*

$$\triangle = \left| \frac{\partial^2 f}{\partial \dot{x}^i \partial \dot{x}^j} \right| \neq 0.$$

The solutions of (4.4) exist in general, any perfect differential being one. But I am unable to find directly the necessary and sufficient restrictions on the $a$'s for nontriviality represented by $\triangle \neq 0$.

It would seem evident, however, that the desired solutions exist much oftener than a groundform exists for affine connections.

Taking the coefficients of affine connection as usual, we investigate the possibility of a special type of metric $f$. This $f$ is to be independent of the parameter $t$ and expansible as a sum of, or as an uniformly convergent series of polynomials in $\dot{x}$, whose coefficients are functions of $x$ alone.

$$(4.5) \qquad f = A + A_i \dot{x}^i + A_{i;j} \dot{x}^i \dot{x}^j + \ldots + {}^{(n)}A_{i, \ldots i_k} \dot{x}^{i}, \ldots \dot{x}^{ik}$$

If $f$ is to be an invariant, the coefficients must be tensors of rank $k$. If we substitute in (4.4) and demand that the result be an identity in $\dot{x}$, we get conditions on each set of coefficients

$$(4.6) \qquad A,_k = 0 \qquad\qquad A = \text{Const.}$$

$$A_{i,j} \dot{x}^i \equiv A_{j,i} \dot{x}^i \equiv A_{j,i} \dot{x}^i,$$

$$\therefore A_{i,j} = A_{j,i}$$

$$\text{and} \quad A_i \dot{x}^i = \frac{d}{dt} \mu(x).$$

The first two terms are trivial and can be neglected. For the rest

$$(4.7) \quad \dot{x}^i \dot{x}^p \dot{x}^m_{\ldots} \left[ k(k-) \left\{ A_{ihp} \Gamma^h_{lm} + A_{ihl} \quad \Gamma^h_{rm} + \ldots \right\} \right.$$

$$\left. - n \left\{ A_{ilm\ldots,p} + A_{ilp\ldots,m} + \ldots \right\} A_{lmp\ldots,i} \right] = 0$$

Substituting for the ordinary partial derivatives in terms of covariant derivatives, and keeping always in mind the complete symmetry of the A's in all their subscripts, we have

$$(4.8) \quad n\, [\, A_{ilmr\ldots/p} + A_{ilmp\ldots/r} + \ldots - A_{lmrp\ldots/i}\,] = 0$$

Changing the subscripts in turn with $i$ and adding, this reduces finally to

$$(4.9) \qquad\qquad\qquad (k)\ A_{ilmp\ldots/r} = 0$$

Theorem 3.—*A necessary and sufficient condition for the existence of an invariant f of the type (4.5, is the vanishing of the covariant derivative of the tensor coefficients of rank higher than two. The first two terms, moreover, must be trivial and $\triangle \neq 0$*

The equations (4.9) again form a system of Koenig, whose conditions of integrability are, on account of the symmetry of the A's,

$$R^{h\ (m)}_{i,jk}\, A_{hi_2 i_3\ldots} + R^{h\ (m)}_{i,jr}\, A_{i,hi_3\ldots} + - \ldots = 0$$

and of course any set that might be derived from these as in (2.10) by further covariant differentiation. In a flat space, these conditions are identically fulfilled, but the most general metric is any $f$ in which only the $\dot{x}$ enter. The Galilean metric is the simplest, containing only terms of the lowest degree admissible for non-triviality. Similarly, in the general Riemannian case, we shall in general obtain a wide choice of admissible $f$ for the given paths; the ground-form is only the non-trivial metric of lowest possible degree.

The parametric case, as also a solution for general $a^i$ by means of expansion in series is too cumbersome. The next step to be discussed will be a reduction of (4.4) to a system of partial differential equations of the first order.

5. At the end of the second section, under (e), we found the same extremals for two integrands that had the form $f$ and $f^2$. If it be demanded that any function $\phi(f)$ be a solution of (4.4) with $f$ itself, we have upon substitution in (4.4)

$$(5.1) \qquad\qquad \phi'' f_{;j}[a^i f_{;i} - \dot{x}^i f_{,i} - f_t] = 0$$

$\phi'' = 0$ gives $\phi = af + b$. $f_{;j} = 0$ gives $f = f(x, t)$ both being trivial cases. If (5.1) is to be true for all at least twice differentiable $\phi$, it follows that

$$(5.2) \qquad\qquad a^i\,\frac{\partial f}{\partial \dot{x}^i} - \dot{x}^i\,\frac{\partial f}{\partial x^i} - \frac{\partial f}{\partial t} \equiv D f = 0$$

This condition is necessary as well as sufficient, and scrutinised closely, is seen to be precisely $f = constant$ along the paths (4.1).

Theorem 4. *A necessary and sufficient condition that the integral of any at least twice differentiable function $\phi(f)$ be stationary over the extremals of*

$$\delta \int f(x, \dot{x}, t)\, a\, t = 0,\ x \sim x_i{}^i$$

$$\dot{x} \sim \dot{x}^j$$

*is that f be constant along those extremals.* As a rule, the auxiliary condition $f = constant$ along the extremals is a restriction on the choice of parameter, and in no case can it modify the form of the Eulerian differential equations.

The equation (5.2) will therefore be adjoined to the system (4.4) Differentiating (5.2) with respect to $\dot{x}$, and substituting in (4.4), a first order system results

$$(5.3) \qquad \frac{\partial \alpha^i}{\partial \dot{x}^j} \frac{\partial f}{\partial \dot{x}^i} - 2 \frac{\partial f}{\partial x^j} \equiv D_j f = 0.$$

Theorem 5. *The existence of solution of (5.2) and (5.3) is necessary and sufficient for the deduction of (4.1) from a variational principle. Then any, at least twice differentiable function of the integrand is also a solution, and the integrand will in all cases be a constant along the extremals.*

A first condition of compatibility is seen by solving (5.3) for $f_{,j}$ and substituting in (5.2)

$$(5.4) \qquad (\alpha^i - \tfrac{1}{2} \dot{x}^j \, \alpha^i_{;j}) \, \frac{\partial f}{\partial \dot{x}^i} - \frac{\partial f}{\partial t} = 0.$$

If this is not identically satisfied, then it must be adjoined to the original system. If the $\alpha$'s are homogeneous of degree two in $\dot{x}$, the solution of the system, if any, is independent of the parameter $t$ though this is not a necessary condition. We might sum up several results in

Theorem 6. *If the solution is independent of t and*

$$\alpha^i (\dot{x}, \lambda \, \dot{x}, t) \equiv \lambda^2 \, \alpha^i (x, \dot{x}, t)$$

*then (5.2) and (4.4) are consequences of (5.3).*

The existence theorems for first partial systems are quite well known, whereas for (4.4), they have yet to be deduced. The conditions for our system (5.2) and (5.3) are seen to be

$$(5.5) \qquad (D D_j - D_j D) f \equiv Q^i_j \frac{\partial f}{\partial x^i} - \frac{\partial \alpha^i}{\partial \dot{x}} ; \frac{\partial f}{\partial x^i} = 0$$

or, eliminating $\dfrac{\partial f}{\partial \dot{x}^i}$ from (5.3), $P^i_j \dfrac{\partial f}{\partial \dot{x}^i} = 0$

$$(D_j D_k - D_k D_j) f \equiv R^i_{j\,k} \frac{\partial f}{\partial \dot{x}^i} = 0$$

where $f_{,i}$ is eliminated by virtue of (5.3) wherever it occurs and

$$(5.6) \qquad -2 P^i_j = \alpha^r \, \alpha^i_{;r;j} - \dot{x}^r \, \alpha^i_{,r;j} - \tfrac{1}{2} \alpha^r_{;j} \, \alpha^i_{;r} - \frac{\partial \alpha^i}{\partial t} ; j + 2 \alpha^i_{,j}$$

$$4 R^i_{jk} = 4 R^i_{kj} = \alpha^r_{;k} \, \alpha^i_{;r;j} 2 \alpha^i_{,k;j} + 2 \alpha^i_{j\,k\,j} - \alpha^r_{;j} \alpha^i_{ir;k} .$$

These new equations, when identically fulfilled, give us complete integrability of the system under discussion. Otherwise, they must also be adjoined to (5.2), (5.3) and (5.4).

The coefficient of (5.6) are connected with each other by means of the relation

(5.7)
$$\frac{\partial P^i_{\;j}}{\partial \dot{x}^k} - \frac{\partial P^i_{\;k}}{\partial \dot{x}^j} = \frac{3}{2}\, R^i_{\;gk}$$

And the usual Riemann-Christoffel tensor is given by

(5.8)
$$\frac{\partial R^i_{\;jk}}{\partial \dot{x}^c} = R^i_{\;jk\,;\,e} = R^i_{\;e;kj}$$

The process of adducing further sets of equations can be further continued. But as we eliminate $\frac{\partial f}{\partial x^j}$ at each step, and there are left only homogeneous equations in not more than $n$ of the equations can be independent. Even if $n$ equations are found to be independent, there can be only the trivial solution $f = f\ (x, t)$ inasmuch as $f; i = 0$

Theorem 7. *A necessary condition that there exist a nontrivial solution of the system (5.2) and (5.3) is that the matrix of coefficients of (5.5) and all other derived equations containing only f; i be of rank less than n.*

The condition will be seen to be sufficient when $f$ is to be non-parametric, or when the $\alpha$'s are given homogeneous of degree two in $\dot{x}$.

If an invariant and non-degenerate $f$ is found to exist, we have a " space " very similar to the Riemann spaces, and, in fact, the condition of non-triviality suggests a groundform

$$g_{ij} = f_{\;\dot{x}^i\;\dot{x}^j} = f; i; j.$$

This can always be justified, if $f$ satisfies a relation of the form

$$\dot{x}^i\,\dot{x}^j f_{;i;\,j} = \phi\,(f) + \frac{d}{dt}\,\psi\,(x, t),$$

$\phi\,(f)$ being any at least twice differentiable function of $f$ itself. The invariance of $f$ will necessarily make $f_{;i;j}$ a tensor of rank two, covariant in the indices. Physical problems can then be discussed, and conformality has a meaning. We get the obvious generalizations of Einstein spaces and of the associate spaces as well that need not be discussed here. The equations (5.3) as also (4.4) are generalizations of the vanishing of the covariant derivatives of the fundamental tensor. The coefficients $R^i_{\;jk}$ and $P^i_{\;j}$ are actually tensors, if the tensor-invariance of the path equations is known.[*]

Developments and geometrical interpretations of the various fundamental conditions in the calculus of variations such as the conditions of Legendre, Jacobi, Weierstrass, the equations of transversality, and the question of conjugate foci,

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[*] All the differential invariants of the " space " can be had by considering the coefficients of our successive derived equations that contain only $\frac{\partial t}{\partial \dot{x}}$.

F. 4

all of which should be fundamental in our new geometry, will be left to a later paper, or to abler analysts. Parallelism and covariant differentiation are fundamental concepts in recent differential geometry, which have received no consideration here. I shall leave all of these aside, and conclude the paper with a series of remarks, all compressed into one section:

6. (*a*) The general inverse variational problem can be stated as follows:

GIVEN: A set of differential equations in any number of variables of any given order, partial or ordinary, and a set of auxiliary conditions not a consequence of the differential equations,

To FIND: Whether or not the manifolds of the solutions of the given equations can be made to coincide for some region with the extremals of a variational problem.

It would seem simpler to discuss the whole problem for ordinary differential equations by means of reduction to a system of ordinary first order differential systems, and then consider the possibility of equating this system to a Plaffian variational principle say, a generalized Hamiltonian principle. This will also give us systems of first order partial differential equations, but unfortunately in several unknowns, for which I have been unable to find any elegant method of solution. When there is to be discussed the problem of fractional differential equations also, no method at all is to be seen. For, the generalized derivative cannot be uniquely defined, as a rule, and may not be real for real variables. The direct problem of the calculus of variations does not seem to have been solved when the generalized derivative enters into the integrand.

(*b*) A space with trivial metric is not necessarily uninteresting. Take for instance, *f* as a perfect differential. The distance of two points is independent of the path, provided *f* is non-singular in regions with the proper connectivity, and often, even then. Such a space will have the additive property of distance on a line

$$D(P_1 \ P_2) + D(P_2 \ P_3) = D(P_1 \ P_3)$$

direction has no significance, and the relativitist who attempts to locate his neighbours by means of light-signals will be in some difficulty unless he has more than one origin of observation.

(*c*) Consider the following differential equations that occur so often in mathematical physics:

$$\ddot{x} - \lambda \dot{y} - v_x = 0$$

(6.1) $$\ddot{y} + \lambda \dot{x} - v_y = 0$$

They are the simplest example of "non-energic" forces in a dynamical system. We see them in the restricted problem of three bodies, the vibrations of an infinite cylinder in a circulating fluid, an etectron in a magnetic field, the gyroscopic pendulum, and so on, even to the Zeemann effect. By inspection, we deduce these when $\lambda$ is a constant from

(6.2) $$\delta \int (\overline{T} + \overline{U}) = 0$$

$$\overline{T}=\tfrac{1}{2}(\dot{x}^2+\dot{y}^2)-\frac{\lambda}{4}(\dot{x}y-x\dot{y}) \quad \overline{U}=U-\frac{\lambda}{4}(\dot{x}y-x\dot{y}).$$

And it is seen that there is still the energy integral in the from $T-U=$ constant. For $\lambda$ not a constant but a function of position, and parameter, we may apply the methods of the previous paragraph. But as the integrand itself is not constant along the extremals, the general problem comes to that of finding the solutions of two equations of the second order, and not our reducible case. This again calls for a profounder study of the relation between the forms of the integrals and the conditions of compatibility.

(d) The method of the paper is also extensible to partial differential equations, and as an example of the most general procedure for a partial differential equation of the second order, we shall show that the equation of wave mechanics, known as Schrödinger's equation, cannot be deduced from a variational principle.

Compare the equation

(6.3)
$$\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}+\frac{\partial^2 u}{\partial z^2}+\Omega\,(p,\,q,\,r,\,s,\,x,\,y,\,z,\,t,\,u)=0$$

$$p=\frac{\partial u}{\partial x}\;;\;q=\frac{\partial u}{\partial y}\;;\;r=\frac{\partial u}{\partial z}\;;\;s=\frac{\partial u}{\partial t}$$

to the Euler equation for

(6.4)
$$\delta\int_{v}f(x,\,y,\,z,\,t,\,p,\,q,\,r,\,s,\,u)\,dv=0.$$

Using again, a factor of proportionality $\rho\,(p,\,q,\,\ldots u)$ we have the following relationships:

$$f_{pp}=f_{zz}=f_{rr}=\rho$$

(6.5)

$$f_{ss}=f_{pz}=f_{zr}=f_{rp}=f_{ps}=\ldots\ldots\ldots\ldots\ldots\ldots=0$$

$$\rho\,\Omega=pf_{pu}+zf_{zu}+rf_{ru}+sf_{su}+f_{px}+f_{zy}+f_{r}+f_{st}-f_{u}$$

Differentiate the last of these partially with respect to $p,\,q,\,r,\,s$ and using the others, we have again a system of first partial differential equations, which is:

$$\sigma=\log\rho$$

(6.6)
$$\frac{\partial\sigma}{\partial x}+p\,\frac{\partial\sigma}{\partial u}-\Omega\,\frac{\partial\sigma}{\partial p}=\Omega_{p}$$

$$\frac{\partial\sigma}{\partial y}+q\,\frac{\partial\sigma}{\partial u}-\Omega\,\frac{\partial\sigma}{\partial q}=\Omega_{q}$$

$$\frac{\partial\sigma}{\partial z}+r\,\frac{\partial\sigma}{\partial u}-\Omega\,\frac{\partial\sigma}{\partial r}=\Omega_{r}$$

$$\frac{\partial\sigma}{\partial t}=-\frac{\Omega_{s}}{\Omega}$$

In the equation of Schrödinger, $\Omega$ has the form $\lambda s + u$ V $(xy)$. The following are the derived equations, easily seen to be incompatible with above :

$(a):$ $(6.7)$      $\left( \Omega_y + q\, \Omega_u \right) \dfrac{\partial \sigma}{\partial p} - \left( \Omega_x + p\, \Omega_u \right) \dfrac{\partial \sigma}{\partial q} = 0$

and two others by cyclic rotation of letters.

$(b):$                                        $\dfrac{\partial \sigma}{\partial p} = \Omega^2 \left( \Omega_x + p\, \Omega_u \right)$

and two others by cyclic rotation of the letters.

These are consistent among themselves, but further derived sets give the contradiction.

Theorem 8. *Schrödinger's wave equation in its general from is not derivable from a variational principle.*

It is well to note here that the $u$ in the wave equation is taken to be complex as also that the classic derivation by Pauli and Heisenberg is based on the physical assumption of Eigenwerte.

$(e)$ The analogy between the derivation of ordinary equations from a minimum principle and that of differential equations from a variational principle is easily worked out.

Given the equations

$(6.8)$               $f^i \left( x^1, x^2 \dots x^n \right) = 0$               $i = 1 \dots n,$

It is desired to equate the whole set to a single minimum principle

$$d\mathrm{F} \left( x_1^{\,1}\ x^2, \dots x^n \right) = 0.$$

Using again our integrating factors $\rho_{ij} \left( x^1 \dots x^n \right)$

$$\xi_{ij}\, f^j = \frac{\partial \mathrm{F}}{\partial x^i}.$$

That gives the following partial differential equations for the $\rho$'s :

$(6.9)$   $\left( \xi_{ij}\, f^j \right)_{,\,k} - \left( \xi_{kj}\, f^j \right)_{,\,i} = 0$

A simple solution is

$$\rho_{ij} = \frac{\partial f^j}{\partial x^i}.$$

Theorem 9.  The equations $f^i$ $\left( x^1, x^2\ x^n \right) 0 =$ can be derived from $d\mathrm{F} = 0$, if the Jacobian $\left| \dfrac{\partial f^i}{\partial x^j} \right|$ does not vanish.  One such F is $\overset{n}{\underset{i=1}{\Sigma}} \left( f^i \right)^2$.

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# THE PHENOMENON OF 'AFTER EFFECT' AND 'INDUCTION PERIOD' IN THE REVERSIBLE PHOTOCHEMICAL REDUCTION OF TUNGSTIC ACID SOL.

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In a previous paper[1] we have shown that the photochemical reduction of the sols of molybdic and tungstic acids by ethyl alcohol follows the zero molecular law in presence of sunlight. Reduction cannot be observed in the dark.

We tried to study the photochemical reduction of these sols in the ultra-violet light received from a mercury lamp. The sols are reduced and the blue colour is seen, but the rate of reaction is very slow, and hence no quantitative work could be done.

In this paper we shall present the result obtained on the period of induction and after effect in the photochemical reduction of tungstic acid by glucose in presence of sunlight.

The appearance of blue colour was followed by a Nutting's spectro-photometer. To isolate any particular region of the spectrum for the case of comparison, a shuttered eye-piece was employed. To obtain extinction coefficient, the Bunsen-Roscoe formula was employed and readings were taken on the 'Density Scale' of the rotating circle. Thus the extinction coefficient is given $\Sigma = \dfrac{D}{t}$ where D is the reading on the density scale and equal to $2 \log_{10} \tan \theta$, $\theta$ being the angular reading and $t$ the thickness in centimeters of the absorbing substance.

The following are the experimental results on the ' period of induction.'

*Table 1*

5c.c. 3 per cent sodium tungstate + 1c.c. $N/1.06$ HCl + 10 c.c. glucose + 10c.c. $HO_2$.

| Time in mins. | Extinction Coefficient | $K_0$ Zero molecular |
|---|---|---|
| 0 | 0 | ... |
| 1 | 0 | ... |
| 2 | 0 | ... |
| 3 | 0·02 | 0·0067 |
| 4 | 0·02 | 0·0050 |
| 5 | 0·03 | 0·0060 |
| 8 | 0·06 | 0·0075 |

| Time in mins. | Extinction Coefficient | $K_0$ Zero molecular |
|---|---|---|
| 12 Taking as initial reading. | 0'08 | 0'010 |
| 14 | 0'10 | 0 010 |
| 16 | 0'12 | 0'010 |
| 18 | 0'14 | 0'010 |
| 20 | 0'16 | 0'010 |
| 22 | 0'18 | 0'010 |
| 24 | 0'20 | 0'010 |

From the above table it is clear that there is a period of induction in this photochemical reduction. It takes 3 minutes to start the reaction and then it gradually increases up to 8 minutes after which if we calculate the rate of reaction we find that it obeys zero molecular law. This period of induction is probably due to the fact that there are aggregated molecules present in tungstic acid which are not active as simple molecules Hence it appears that by the action of light at first the aggregated molecules break up into simple molecules and then the reduction begins.

With a view to study the after effect phenomenon, the solution was exposed to light for some time and then it was kept in the dark and the readings were taken. The following are the experimental results : —

*Table 2*

Concentration of solution as given in table 1. Exposed to sunlight for 20 minutes.

| Time in mins. | Extinction Coefficient | $K_0$ Zero molecular |
|---|---|---|
| 20 | 0'16 | |
| 24 | 0'12 | 0'010 |
| 28 | 0'07 | 0'011 |
| 30 | 0'04 | 0'012 |
| 32 | 0 | 0'013 |

The above results show that the reduced tungstic acid, which yields a coloured solution is oxidised to colourless tungstic acid when kept in the dark and the photochemical reduction of tungstic acid sol appears to be reversible. The constants calculated for the oxidation of the reduced tungstic acid is found to be increasing. The reversible reaction, *viz.*, the oxidation is at the beginning a little balanced by the direct action due to after effect.

## INFLUENCE OF CARBON DIOXIDE IN THE REACTION

In order to study whether the oxidation of the reduced tungstic acid is due to the reverse reaction or to the action of air we carried out the experiments in an atmosphere of carbon dioxide. The following are the results :

*Table 3*

Exposed to sunlight.   Concentration of the solution as in table 1.

| Time in mins. | Extinction Coefficient | $K_0$ Zero molecular |
|---|---|---|
| 0 | ... | ... |
| 3 | 0·25 | ... |
| 12 | 0·40 | 0·017 |
| 21 | 0·55 | 0·017 |
| 30 | 0·72 | 0·0174 |
| 39 | 0·86 | 0·0170 |
| 48 | 0·95 | 0·0156 |
| 51 | 0·97 | 0·0150 |
| 60 | 1·02 | 0·0135 |
| 65 | 1·02 | ... |
| 70 | 1·02 | ... |

From the above table we see that the rate of reduction is much greater than that observed in table 1.   The reduction is complete in one hour, after that there is no increase in the extinction coefficient.

In order to find the 'after effect' we exposed the solution in sunlight for some time and then kept it in the dark.   The experiment is carried out in an atmosphere of carbon dioxide in order to stop the oxidation of the reduced acid by air.   The results are given below.

*Table 4*

Exposed for 16 minutes and then brought in the dark.

| Time in mins. | Extinction Coefficient | $K_0$ Zero molecular |
|---|---|---|
| 16 | 0·48 | ... |
| 19 | 0·51 | 0·010 |
| 22 | 0·53 | 0·008 |
| 25 | 0·53 | ... |
| 30 | 0·53 | ... |

Exposed for 39 minutes and then brought in the dark.

| Time in mins. | Extinction Coefficient | $K_0$ Zero molecular |
|---|---|---|
| 39 | 0·85 | ... |
| 42 | 0·88 | 0·010 |
| 45 | 0·90 | 0·008 |
| 48 | 0·91 | 0·0067 |
| 51 | 0·91 | ... |
| 55 | 0·91 | ... |

The foregoing results conclusively prove that there is influence of after effect for some time and then a stationary state is reached when the reaction is studied in absence of air.    This further shows that by passing carbon dioxide no oxidation of the reduced acid is observed and we are of opinion that the apparent reversibility of the reaction is due to the oxidising action of air.

The phenomenon of after effect has been shown to be present in several photochemical reactions by Mukherji and Dhar.[2]   We are of opinion that the after effect is due to the increase in the life period of the activated molecules in solution.

We desire to the express our best thanks to Prof. N. R. Dhar for his kind interest and encouragement in the progress of this work.

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# THE ABSORPTION SPECTRA OF LITHIUM HALIDES AND THE LATENT HEAT OF EVAPORATION OF LITHIUM.

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The latent heat of evaporation of a metal is usually determined from its vapour pressure data, according to the equation,

$$L_M = \frac{R\,T_1\,T_2}{T_1 - T_2} \log_e \frac{P_1}{P_2} \qquad \ldots \qquad \ldots \qquad \ldots \quad (1)$$

where R is a constant $= 1.985$, and $P_1$ and $P_2$ are the vapour pressures of the metal M at the absolute temperatures $T_1$ and $T_2$ which are close to each other. The vapour pressure of lithium is yet unknown, hence the latent heat of evaporation has not yet been determined.

In the present paper I have determined the latent heat of evaporation of lithium by studying the absorption spectra of the vapours of the halides of lithium experimentally and interpreting the results of the experiments in the light of Franck's[1] theory of photo-dissociation of alkali-halides. A short theory of the experiment is given below.

## THEORY

In the normal molecule of a diatomic halide the two parts of the molecule have opposite charges and they are bound together by a large electrostatic force of attraction as,

$$M^+ \;\underline{\qquad}\; X^-$$
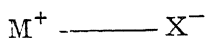
When such a molecule is exposed to the energy from a source of continuous light, light of suitable frequency is absorbed and the molecule is raised to higher electronic state, the result is that the electron passes from the halogen to the metal and the electrostatic force is destroyed. Now the combination,

$$M \;\underline{\qquad}\; X$$

being unstable, dissociation takes place and the molecule is split up into two normal atoms. At this stage of atomic dissociation, the two atoms can separate with any amount of kinetic energy; hence light is absorbed continuously from the source and the absorption begins from a long wavelength limit $\lambda$, and gradually extends towards the shorter wavelength side. We have the relation

$$R = Q + \tfrac{1}{2}\,D_{x_2} + L_M - L$$

$$\text{or } L_M = R + L - [Q + \tfrac{1}{2}\,D_{x_2}] \qquad \ldots \qquad \ldots \qquad \ldots \quad (2)$$

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$$\text{where R } = \text{N}\,\frac{h\nu}{\text{J}} \qquad . \qquad \cdots \qquad \cdots \quad (3)$$

$$= \frac{286000}{\lambda}$$

where $\lambda$ is the long wavelength limit of absorption in Å. units, D = the heat of dissociation of the halogen, $L_M$ and $L$ are the latent heats of the metal and the halide respectively, and Q = heat of formation of the compound in the solid state.

R is obtained from the results of the absorption experiments, and the other quantities are taken from Landolt and Börnstein's Tables.[2] Thus, the only unknown quantity $L_M$ can be calculated.

### THE EXPERIMENT.

In order to study the absorption spectra, I took anhydrous lithium halides and vaporised them in the Vacuum Graphite Furnace[3] of this laboratory in an atmosphere of nitrogen. Continuous light was passed through the vapours and their absorption spectra photographed.

The source of continuous light was a specially constructed hydrogen discharge tube run by a high current transformer. The spectrum was photographed with Hilger E3 quartz spectrograph, and micro-photograms were taken on the Carl Ziess Microphotometer at Patna laboratory. The curves obtained are given in Fig. II.

### THE RESULTS OF THE EXPERIMENT.

The photographs show continuous absorption beginning from an ill-defined long wavelength limit and gradually extends towards the shorter wavelength side. In the case of the bromide and the iodide there are re-transmissions and again absorption. The first absorption limits and the corresponding values of R are tabulated in Table I below :—

*Table I*

| Halide | Beginning of absorption in A. U. | R in k.cals. |
|---|---|---|
| LiF | 2160 | 132·4 |
| LiCl | 2420 | 118·0 |
| LiBr | 2735 | 104·5 |
| LiI | 3640 | 78·5 |

The other data (taken directly from Landolt and Börnstein's Tables) is collected in Table II given below :—

*Table II*

| Halide | Q | $\frac{1}{2} D_{x_2}$ | $L_M$ |
|--------|------|------|------|
| LiF | 120 | 38* | 55 |
| LiCl | 97 | 29 | 37 |
| LiBr | 87 | 23 | 35·7 |
| LiI | 71·3 | 17·3 | 40 |

CALCULATIONS

We have the equation (2) in the case of lithium halide as

$$L_{L_i} = R - Q - \tfrac{1}{2} D_{x_2} + L$$

Substituting the values for the quantities on the right-hand side of the equation we have,

In the case of LiF,

$$L_{Li} = 132\cdot4 - 120 - 38 + 55$$
$$= 29\cdot4 \quad \text{k.cals.}$$

In the case of LiCl,

$$L_{Li} = 118 - 97 - 29 + 37$$
$$= 29\cdot0 \quad \text{k.cals.}$$

In the case of LiBr,

$$L_{Li} = 104\cdot5 - 87 - 23 + 35\cdot7$$
$$= 30\cdot2 \quad \text{k.cals.}$$

In the case of LiI,

$$L_{Li} = 78\cdot5 - 71\cdot3 - 17\cdot3 + 40$$
$$= 29\cdot9 \quad \text{k.cals.}$$

Thus the values of $L_{Li}$ are :—

*Table III*

| Halide | $L_{Li}$ |
|--------|------|
| LiF | 29·4 |
| LiCl | 29·0 |
| LiBr | 30·2 |
| LiI | 29·9 |

* $D_{F_2}$ =76. k.cal. This value has been determined by the author and reported in the *Proc. Roy. Soc.* 136 (1932), p. 76,

Therefore the mean value of
$$L_{Li} = (29{\cdot}6 \pm {\cdot}6) \quad \text{k.cals.}$$

*Re-transmission.*

In the cases of the absorption due to the bromide and the iodide of lithium, we obtain retransmission.

The first absorption corresponds to the dissociation,
$$LiX = Li + X - h\nu_1$$
while the second absorption is due to the splitting up of the molecule into one normal and another excited atom. Assuming that the halogen is excited, we have,
$$LiX = Li + X_e - h\nu_2$$
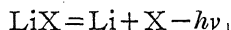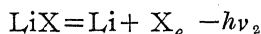
If $\triangle\nu$ is the difference of frequency corresponding to the two absorptions $h(\nu_2 - \nu_1)$, we have E the energy of excitation,

$$E = \frac{\triangle\nu}{8100} \quad \text{volts} \qquad \ldots \qquad \ldots \qquad \ldots \quad (4)$$

The actual values observed as the result of these experiments are:—

| | | | | |
|---|---|---|---|---|
| LiBr ... | ... | $\triangle\nu = 3770$ ... | ... | E = 0·46 volts |
| LiI ... | ... | $\triangle\nu = 7300$ ... | ... | E = 0·91 volts |

The frequency differences obtained by other spectroscopic methods are:

| | | | | |
|---|---|---|---|---|
| For Br... | ... | $\triangle\nu = 3633$ ... | ... | E = 0·448 volts |
| For I ... | ... | $\triangle\nu = 7600$ ... | ... | E = 0·938 volts |

Figs. $I_b$ and $I_c$ show the retransmissions and $II_c$ and $II_d$ and show the micro-photograms for the retransmission plates.

## THE DISCUSSION OF THE RESULTS.

According to the present determination, the latent heat of evaporation of Lithium is 29·6 k. cals. Unfortunately no work has yet been done on the accurate determination of the vapour pressure of Lithium, hence it is not possible to check the above value. But some rough calculation can be given in support of the value obtained.

The vapour pressure of sodium has been investigated in great detail by Ladenburg and Thiele.[*] They expressed the observed vapour pressure by the empirical formula,

$$\log p = -\frac{26077}{4{\cdot}573 \times T} - 1{\cdot}178 \log T + 11{\cdot}329 \qquad \ldots \quad (5)$$

where $p$ is the vapour pressure in mms. of mercury and T is the absolute temperature, and the number 26077 stands for $L_{Na}$ (in cals.).

Now the constant in the formula contents the term $\frac{3}{2} \log M$, as the "chemical constant" and is given by

$$C = -1{\cdot}588 + \tfrac{3}{2} \log M \quad \ldots \qquad \ldots \qquad \ldots \quad (6)$$

where M is the atomic weight of the element.

The chemical constant of lithium should be less than that of sodium, by $\frac{3}{2} \log \frac{23}{7}$, *i.e.*, by 0·775. Further as lithium and sodium are very much alike in chemical and physical properties, we suppose that their atomic specific heat terms are almost equal, and their dissociation into atoms is also alike. We thus obtain in the case of Lithium:

$$\log P_{Li} = -\frac{L_{Li}}{4·573 \times T} - 1·178 \log T + 10·554 \qquad \ldots \qquad \ldots \quad (7)$$

By taking the conditions corresponding to the boiling point of Lithium, the value of $L_{Li}$ can be approximately calculated. According to Landolt and Börnstein's Tables the boiling point of Lithium is $T^0 = 1400^0$ C or $1673^0$ Abs. Putting $T = 1673$ and corresponding $p = 760$ mms. in the formula (7), we have,

$$\log 760 = -\frac{L_{Li}}{4·573 \times 1673} - 1·178 \log 1673 + 10·554 \qquad \ldots \qquad \ldots \quad (8)$$

which gives

$$L_{Li} = 29570 \text{ cals.}$$
$$= 29·57 \text{ k.cals.}$$

Thus it can be seen that the value of $L_{Li} = 29·6$ k. cals. found out by this new method is in excellent agreement with that expected from the theory. Though the method applied to check the present result is rough still it can be said that the value is not much far from the real one.

As regards the excitation potentials of bromine and iodine, the results obtained by the experiments are quite near the actual values. Taking into consideration the difficulty in reading the exact beginning of absorption, from the plate we see·that the results obtained are quite true within experimental errors.

### (*Note added during proof correction* )

After this paper was sent for publication the author has come across a paper by A. Borgos[5] in which the quantity is calculated from the determinations of the vapour pressures of lithium. He gets 28·2 k.cals. The two methods—quite independent of one another—show excellent agreement in the result.

### SUMMARY.

In the present paper the absorption spectra of the halides of lithium in the vapour state have been obtained. The absorption is continuous beginning gradually from an ill-defined long wavelength limit as in the case of other alkali halides. Using the relation,

$$h\nu = R = Q + \tfrac{1}{2} D_{x_2} + L_{Li} - L$$

where R = " atomic heat of dissociation " obtained from the long wavelength limit of absorption, we obtain $L_{Li}$ since the other quantities are known.

$L_{Li}$ comes out to be

$$(29\cdot6 \pm \cdot6) \text{ k. cals. per gm. atom}$$

In the case of LiBr, and LiI retransmissions and second absorptions were obtained. Assuming that the second absorption corresponds to the splitting up of the molecule into a normal metal and an excited halogen atom the energy of excitation of the atom is calculated from the frequency difference between the two absorption limits on the long wavelength side. The excitation potentials thus obtained are : —

| | | | | |
|---|---|---|---|---|
| Br | ... | ... | ... | 0·46 volt |
| I | ... | ... | .. | 0·91 volt |

## ACKNOWLEDGMENTS

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a
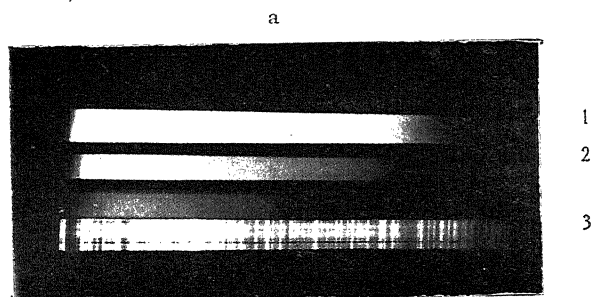
LiCl
(absorption begins at λ 2420)

1
2
3

b
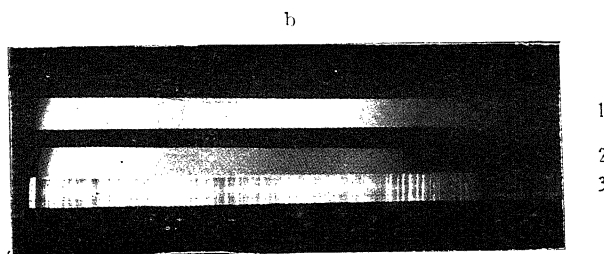
LiBr
(absorption begins at λ 2735)
△ν = 3770

1
2
3

c
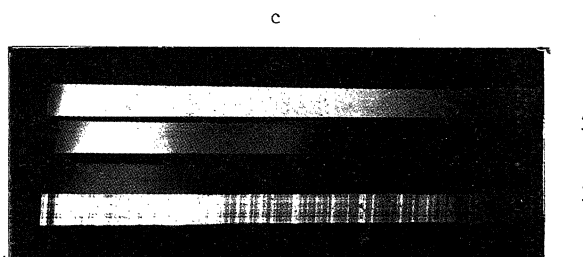
LiI
(absorption begins at λ 3640)
△ν = 7300

1
2
3

1 — continuous
2 — absorption
3 — Cu-arc

**Fig. 1**

λ 2420

λ 3640

Δν 7300

c-LiI!

λ 2160

c-LiBr

λ 2735

Δν 3770
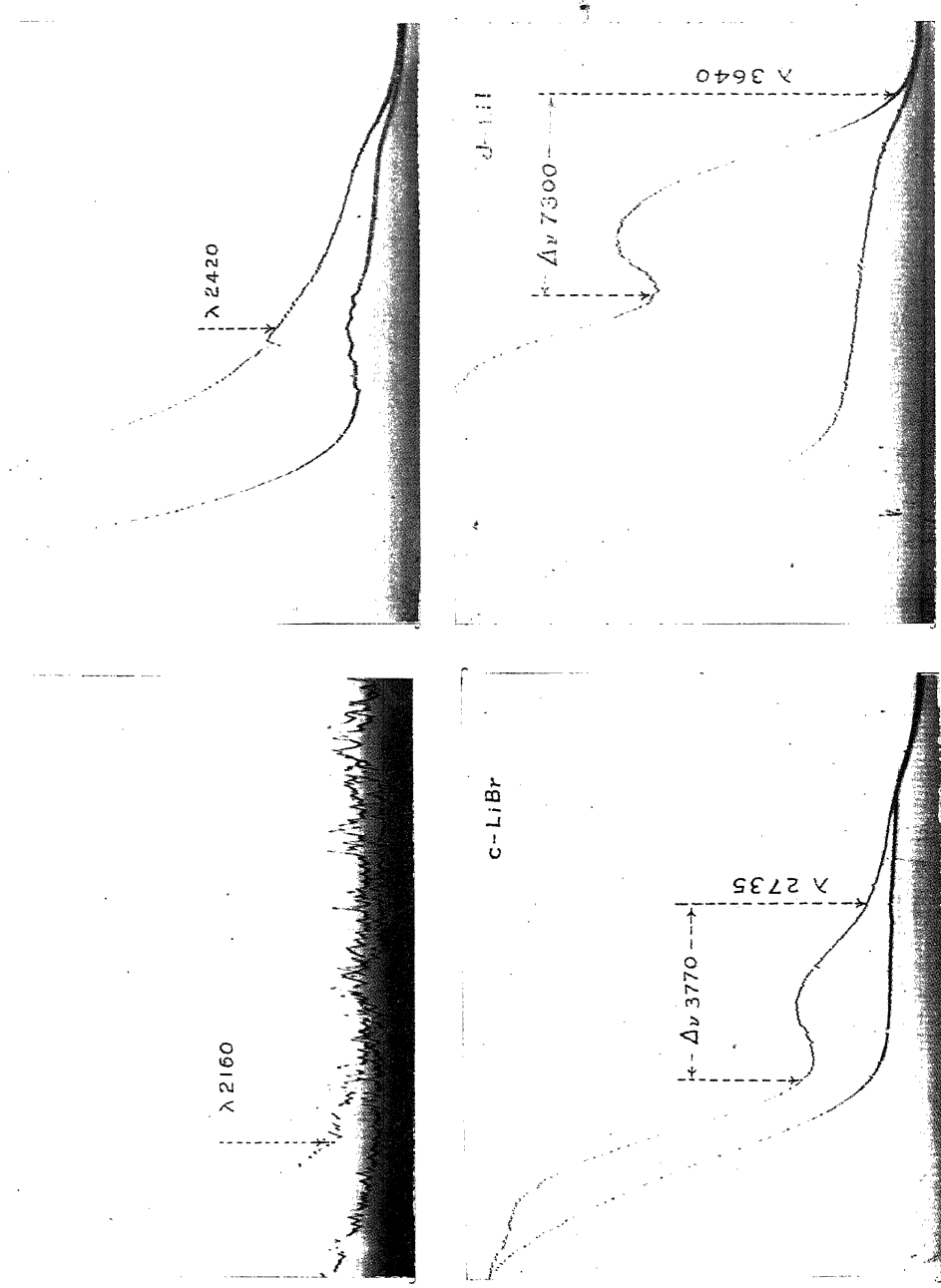
Fig. II

(The Microphotometer used was Carl Zeiss make)

# THE EFFECT OF THE VELOCITY OF HAMMER UPON THE QUALITY OF A NOTE FROM THE STRUCK STRING

## PART I

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Communicated by Dr. R. N. Ghosh.
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## INTRODUCTION

The problems connected with the vibrations of strings with a special reference to piano and the art of piano-playing are of much interest to a physicist as well as to an artist and afford an extensive field for investigation. The particular point whether it is possible to vary the quality of a note along with the loudness, *i.e.*, with the hammer-velocity or independently of it has been much studied and discussed. It has been stated that the quality of a note, apart from its loudness, depends on the relative intensity of the fundamental tone and its several harmonics and that the differences in the quality are noticeable according as whether the same note is struck with a sharp blow or a heavy pressure, and we are led to the conclusion that the intensities of the fundamental tone and its several harmonics are either functions of one variable only or of two or more variables. Now those adhering to the single variable hypothesis assert that the quality of a note may vary according to its loudness; this only requiring that the intensities of the various components shall be different functions of the same variable instead of being its multiples. We are also told that the harmonics of a note are always most prominent when the note has been produced by the least possible hit by the fingers, in fact, when it is practically produced by pressure alone.

Recently Mr. William Braid White[2] made certain observations concerning the variations of quality of a piano-note with its loudness. In his paper three pictures of the sound emitted from the same key, with three different artistic touches, of a concert grand piano are given, in which every curve has its own individual shape corresponding to its individual loudness. These pictures were obtained with the aid of a microphone in conjunction with an amplifier, thus rendering the sound pass through a net-work of electrical system, before it was actually recorded. By a study of these curves he concludes that "every difference of hammer-velocity connotes a difference both of intensity and of tone-color and that it is not possible for a pianist to obtain from the same note two sounds of different color-values (component structures) without a corresponding change of loudness."

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In this present paper also a study of the same point has been made by means of a different but direct experimental method and, as will be seen, the results obtained are not in agreement with the conclusions of Mr. W. B. White. In these experiments the loudness of a note was varied by varying the hammer-velocity and the resulting time-displacement curve of one fixed point of the string was studied. It was found that the character of the curve hardly alters although the loudness changes by about 25% or more. Details of the experimental work and discussions are given below.

## EXPERIMENT

The apparatus used in the present investigation was very simple. A piano was not used but instead a steel wire was stretched between two bridges, 140 cms. apart (of which one was a flat bridge and the other a sharp-edged one) along a wooden board, 150 cms. long, 12 cms. broad and 3 cms. thick. Since the temperature variation of the room did not exceed one or two degrees, the tension of the stretched string was assumed to be almost constant. The hammer used was not covered with felt but with a rubber tubing and mechanically it was so arranged that it could strike the wire with widely different velocities by simply allowing it to fall freely from different heights. The actual vibrations set up in the wire were shadow-graphed as is usually done by means of a falling-plate arrangement. A few shadowgraphs of the vibrations of the string obtained by this method, when the hammer, the striking point and the other factors connected with the string were kept constant and only the hammer-velocity was changed, are shown here.

In Fig. (A) curves (1), (2), (3) and (4) are the vibration curves of the string with a particular hammer of mass about 14·6 grams and the striking point at a distance of about 37·5 cms. from the flat bridge. The actual hammer-velocity of impact was not measured, but the hammer was allowed to fall freely upon the string from different heights ranging from about 2·5 cms. to about 6·5 cms. Since no external forces other than the frictional and the gravitational acted upon the hammer before it impinged upon the string—the hammer being in effect an inverted compound pendulum—it is quite obvious that the hammer velocities in these cases differed fairly widely from each other and thus the object of the experiment, i.e. varying the hammer-velocity without much changing the mode of this variation was quite fulfilled.

In Fig. (B) curves (1), (2), (3), and (4) are the vibration curves of the same string with a hammer of effective mass about 12·6 grams and the striking point at a distance of 30 cms. from the nearest bridge. In this case also the heights from which the hammer was allowed to fall freely ranged from 2·5 cms. to 6·5 cms.

A very slight difference in the curves Fig. (A) (1), (2), (3) and (4) and also in the curves Fig. (B) (1), (2), (3) and (4) which may be noticed on careful examination is due to the fact that in taking the shadowgraphs, the velocity of the running

photographic plate on which these vibration-curves were recorded was not exactly the same in all the cases. It differed a little in every case so that the elongations of these curves, but not their character, are a bit different from each other. These differences in the elongation, however, have nothing to do with the variations in the hammer-velocity but are mainly due to the non-similarity in the velocity of the recording photographic plate. This point has been confirmed experimentally by keeping the hammer-velocity constant and taking different shadowgraphs with alling-plate velocities differing a little from each other. All such curves (not produced here) indicated the same type of difference due to difference in elongations although the hammer-velocity was not changed. But even then the changes, if any, in the character of the curves Fig. (A) as well as Fig. (B) are not so marked as we find in the curves given by W. B. White.

In curves Fig. (C) (1), (2), (3) and (4) this effect, due to the velocity of the photographic plate not remaining the same was reduced to a minimum; care being taken to keep the velocity of the running photographic plate the same in all the four cases. The effective mass of the hammer used was about 11·9 grams. The distance of the striking point from the flat bridge was 18 cms. The heights from which the hammer fell freely ranged from 2·8 cms. to 7·4 cms. We can see at once that all these curves have the same shape or character although their amplitudes are different from each other.

Thus all the shadowgraphs so far obtained by us have confirmed beyond doubt that if the hammer, the striking point and the other factors of the string remain the same, as is the case with a piano, the resulting vibration of the string or, if preferred, the quality of the sound emitted should remain the same, no matter whatever variations in the hammer-velocity may take place. In fact, a study of all the curves obtained under several different conditions clearly shows that the variation in the hammer-velocity alters only the amplitude of the sound emitted and not its quality. That is to say, for any individual quality of a note there may correspond any number of different amplitudes. Hence we find that the quality of a note is quite independent of its amplitude.

Now in order to test whether the flexural vibrations of the stem of the hammer have any effect upon the quality of the note, we used a special hammer, the stem of which was made out of a piece of thick brass wire so that these effects may be magnified. The effective mass of this hammer was about 9·5 grams and the striking distance was 17·5 grams from the nearest bridge. Two cases of the different modes of giving rise to two different types of flexural vibrations in the stem of the hammer are shown in Fig. (D) curves (1) and (2). It is clearly seen that these curves differ from each other in character as well as in amplitude. It may also be noted that the curve with the larger amplitude appears to be simpler in structure than the other one with the smaller amplitude.

The discussion of the results obtained along with a note on the energy imparted to the struck string and its distribution amongst the partials will be given in Part II of this paper.

F. 6

In conclusion I thank Dr. R. N. Ghosh, D.Sc. for his guidance and help throughout the work. I also wish to express my thanks to the authorities of the Osmania University, particularly to Principal Mohammed Abdur Rahaman Khan for granting me a scholarship which enabled me to stay at Allahabad and carry out this work.

*References.*

[1] G. H. Bryan, *Nature*, **91**, 246, 1913.

[2] W. B. White, *Amer. Acoustic Soc. Journ.* **1**, 357, 1930

Fig. (A)  (1)

        (2)

        (3)

        (4)

Fig. (B)  (i)

        (2)

        (3)

        (4)

Fig. (C)  (1)

        (2)

        (3)

        (4)

Fig. (D)  (1)

        (2)

# ON THE CLASSIFICATION OF THE SPECTRAL LINES OF
## $CL_V$ AND $CL_{IV}$

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Received September 3, 1932.

## 1. INTRODUCTION

Chlorine is one of those elements the spectrum of which has been studied widely in the Schumann and Lyman regions for the normal and ionised states. The chief workers in the field are Millikan and Bowen,[1] who while studying the nature and position of $pp'$-group, excited the spectrum up to the 7th degree of ionisation. The other principal workers in the field are Turner,[2] who photographed the principal lines of the arc spectrum in the Schumann region, Bloch and Bloch,[3] Asagoe,[4] Kiess and de Bruin,[5] and Majumdar.[6] Most of these workers confined themselves to the lower ionised states of the atom. At the present time the classification of the lines up to the second state of ionisation is known.

The object of the present work is the classification of the lines of chlorine in the fourth and fifth stages of ionisation. I have taken, as my starting point, Bowen's work[7] in the Schumann region on the series spectra of $Cl_{II}$, $Cl_{III}$ $Cl_{IV}$ and $Cl_V$. For $Cl_V$ he gave a number of lines in the region between λ 390·07, and 894·15 and put forward a scheme of classification along with it; later he published a classification of a number of lines for $Cl_{IV}$ in region between λ 463·011 to 985·749. But the nature of the spectra of these ions in the visible and ultraviolet is totally unknown, though lines due to them have been given by the Blochs, Asagoe and others.

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## II. Theoretical consideration in the spectra of 3-valence electron systems

The electron structure in this system is as follows :

*Table 1.*

| Electron structure | Term | Electron structure | term |
|---|---|---|---|
| $ns^2np$ | $^2P$ | | |
| $ns^2nd$ | $^2D$ | $ns.np^2$ | $^4P, {}^2D, {}^2P, {}^2S$ |
| $ns^2(n+1)s$ | $^2S$ | | |
| $ns^2(n+1)p$ | $^2P$ | $np^3$ | $^2D, {}^2P, {}^4S$ |

($n$ has the value 3 in the case of Cl$_V$)

The first four rows on the left give the terms from the normal configuration $ns^2$ of the next higher ion, the first row on the right hand gives the terms from $ns\,np$ — configuration of the ion, and in the second row, those terms which arise from $np^3$ are recorded.

## III. Position of the multiplets due to transitions between the levels

The irregular doublet law has been fruitful in its application to the case of doublet spectra. For the system of successive elements (neutral and ionised) possessing the same structure as Cl$_V$ the data are given in the following tables :

*Table 2.—Application of irregular doublet law.*

| Combination | Element | $\nu$ | $\triangle\nu$ |
|---|---|---|---|
| | Al$_I$ | 7616 | |
| | | | 8134 |
| | Si$_{II}$ | 15751 | |
| | | | 7927 |
| $(3s^2.4s)^2S - (3s^2.4p)^2P$ | P$_{III}$ | 23678 | |
| | | | 8597 |
| | *S$_{VI}$ | 32275 | |
| | | | 7622 |
| | Cl$_V$ | 39897 | |
| | Al$_I$ | 32325 | |
| | | | 46731 |
| | Si$_{II}$ | 79056 | |
| | | | 37265 |
| $(3s^2\,3p)^2P - (3s^23d)^2D$ | P$_{III}$ | 116321 | |
| | | | 34869 |
| | S$_{IV}$ | 151189 | |
| | | | 33202 |
| | Cl$_V$ | 184401 | |

* Given by Bowen ; appears to be doubtful.

The application of the regular doublet law to these spectra is shown in Table 3. The screening constant is computed from the usual Sommerfeld formula,

$$\triangle \nu = \frac{a^2 R(z-\sigma)^4}{n^3 l\,(l+1)}.$$

*Table 3.—Screening constant and differences from Sommerfeld formula.*

| Term | Element | $\triangle \nu$ | $\sigma$ | $\triangle \sigma$ |
|---|---|---|---|---|
| $(3s^2\,3p)^2p$ | Al$_I$ | 112 | 7·325 | |
| | Si$_{II}$ | 287 | 6·820 | 0·505 |
| | P$_{III}$ | 566 | 6·493 | 0·327 |
| | S$_{IV}$ | 951 | 6·813 | 0·180 |
| | Cl$_V$ | 1491 | 6·160 | 0·153 |
| $(3s^2\,4p)^2p$ | Al$_I$ | 15 | 8·740 | |
| | Si$_{II}$ | 60 | 7·976 | 0·764 |
| | P$_{III}$ | 136 | 7·609 | 0·367 |
| | S$_{IV}$ | 210 | 7·761 | −0·143 |
| | Cl$_V$ | 375 | 7·474 | 0·287 |

## IV. Classification of the lines

From these tables we at once arrive at the following conclusions :

(1) The position of $4s \leftarrow 4p$ transition is at about $\nu$ 39,000

   ,,    $3p \leftarrow 3d$ ,,   ,,   $\nu$ 185,000

   ,,    $4p \leftarrow 4d$ ,,   ,,   $\nu$ 48,000

(2) The probable separation of the terms :

    $3p - 1491,$

    $4p - \phantom{0}370$

    $3d - \phantom{00}34$

With the aid of these considerations the spectrum of Cl$_V$ is classified. Classified lines together with the term values are given in Table 4. There was practically no ambiguity in the identification of the lines. The transition $4p \leftarrow 4d$ falls in the fluorite region, for which the data were not available.

*Table 4.*

| λ | I | $\nu$(vac) | Combinations |
|---|---|---|---|
| 309·07 | 1 | 256364 | $(3s^2.3p)^2P_{\frac{1}{2}} - (3s^2.4s)^2S_{\frac{1}{2}}$ |
| 392·39 | 1 | 254848 | $(3s^2.3p)^2P_{\frac{3}{2}} - (3s^2.4s)^2S_{\frac{1}{2}}$ |
| 538·032 | 5 | 185863 | $(3s^2.3p)^2P_{\frac{1}{2}} - (3s^2.3d)^2D_{\frac{3}{2}}$ |
| 542·297 | 6 | 184401 | $(3s^2.3p)^2P_{\frac{3}{2}} - (3s^2.3d)^2D_{\frac{5}{2}}$ |
| 542·395 | 3 | 184367 | $(3s^2.3p)^2P_{\frac{3}{2}} - (3s^2.3d)^2D_{\frac{3}{2}}$ |
| 2205·71 | 5 | 39896·8 | $(3s^2.4s)^2S_{\frac{1}{2}} - (3s^2.4p)^2P_{\frac{3}{2}}$ |
| 2529·53 | 2 | 39521·2 | $(3s^2.4s)^2S_{\frac{1}{2}} - (3s^2.4p)^2P_{\frac{1}{2}}$ |

Terms.

$(3s^2\ 3p)\ ^2P_{\frac{1}{2}}$   562150

           1516

       $^2P_{\frac{3}{2}}$   560634

$(3s^2\ 3d)\ ^2D_{\frac{3}{2}}$   376267

           34

       $^2D_{\frac{5}{2}}$   376233

$(3s^2\ 4p)\ ^2P_{\frac{1}{2}}$   266265

           376

       $^2P_{\frac{3}{2}}$   265889

$(3s3p^2)$   $^2D_{\frac{3}{2}}$   448891

           71

       $^2D_{\frac{5}{2}}$   448820

       $^2S_{\frac{1}{2}}$   415507

       $^2P_{\frac{1}{2}}$   404219

           962

       $^2P_{\frac{3}{2}}$   403257

$3p^3$   $^4S_{\frac{3}{2}}$   256462

The term values in the spectra of $Cl_{IV}$ and $Cl_V$ were obtained by Bowen from an application of Moseley law of extrapolation of the $(\nu/R)^{\frac{1}{2}}$ values from the preceding spectra. With data now available it is possible to apply a Rydberg formula to the two $p$-terms, from which the value of $3s^2 3p^2 P_{\frac{1}{2}}$ term, corresponding to the ionisation potential, can be calculated. For $Cl^V$ this comes out to be 69·36 volts.

The older value of Bowen obtained from the application of Moseley law is 67·2 volts and is obviously too small.

## V. Spectrum of Cl$_{IV}$

The 4-valence elements in this group consist of Si$_I$ , P$_{II}$, S$_{III}$ and Cl$_{IV}$. The first three of this group have been analysed by Fowler,[5] Bowen[9] and Ingram,[10] respectively. In the case of Cl$_{IV}$ Bowen photographed the resonance lines and the lines due to the $pp'$ group. They will be found in Table 8. I have included them in my list because they are required for calculating the term values. These ions in their lowest state have the electron configuration $3s^2 3p^2$, which give rise to five low energy levels $^3P_{0,1,2}$; $^1D_2$; $^1S_0$. The next higher group of levels are from the configuration $3s^2 3p4s$. The following table gives the electron configuration along with the terms arising from them. The underlined terms are those that are identified from analysis.

*Table 5.*

| Electron configuration | Adopted prefix | Terms |
|---|---|---|
| $1s^2 2s^2 2p^6 3s^2 3p^2$ | $3p$ | $^3\underline{P}$   $^1D$   $^1S$ |
| (         ) $3s^2 3p4s$ | $4s$ | $^3\underline{P}$   $^1\underline{P}$ |
| (         ) $3s3p^3$ | $3p'$ | $^5S$,   $^3D$,   $^3P$,   $^3S$,   $^1D$,   $^1P$ |
| (         ) $3s^2 3p3d$ | $3d$ | $^3F$   $^3D$,   $^3P$   $^1F$   $^1D$   $^1P$ |
| (         ) $3s^2 3p4p$ | $4p$ | $^3\underline{D}$,   $^3\underline{P}$,   $^3\underline{S}$,   $^1\underline{P}$,   $^1\underline{D}$,   $^1\underline{S}$ |

## VI. Correlation of 3 and 4-valence systems

In the ground state of the 3 -valence spectra we have two fundamental levels $^2P_{\frac{1}{2}}$ and $^2P_{\frac{3}{2}}$. If an $ms$-electron is coupled to it these two levels split up into four, such as $^3P_0$, $^3P_1$ and $^3P_2$, and $^1P_1$. If the value of $m$ is high it is found that two of these ($3p_0$ and $^3P_1$) tend to converge to a limit and the other two ($^3P_2$ and $^1P_1$) to another limit, the former set corresponds to $^2P_{\frac{1}{2}}$ and the latter set to $^2P_{\frac{3}{2}}$. We give below a table showing these relations in the cases under discussion.

*Table 6.*

|  | Si$_I$ | P$_{II}$ | S$_{III}$ | Cl$_{IV}$ |
|---|---|---|---|---|
| $ms$ ($^3P_0-^3P_2$); $ms$ ($^3P_1-^2P_2$) | 272 ; 195 | 528 ; 381 | 449 ; 494 | 1442 ; 10 |
| $(m+1)s$ ($^3P_0-^3P_2$); $(m+1)s(^3P_1-^3P_2)$ | 281 ; 214 | 546 ; 435 | 925 ; 772 | ... |
| $(m+1)s$ ($^3P_0-^3P_2$); $(m+2)s(^3P_1-^3P_2)$ | 284 ; 231 | ... | ... | ... |
| Limit $^2P_{\frac{1}{2}}-^2P_{\frac{3}{2}}$ for M+ | 287 | 566 | 951 | 1516 |

Following Goudsmidt and Humphreys[11] it can be shown that where Russell-Saunders coupling is operative the $(3s^2 3p4s)$ $^3$P separations should be smaller than those of $(3s^2 3p)^2$P. But the total $(3s^2 3p4p)$ P-separations will not be affected. As is known from other spectra higher nuclear charge is favourable to a change of coupling from the Russell-Saunders type to the $(jj)$ type. Thus the $s^2ps$ configuration with Russel-Saunders coupling gives $^3$P and $^1$P terms. When we go over to limiting $(jj)$ coupling we still have 4 levels characterised by the same inner quantum values, but two of them having values 0, 1 lie relatively close together and are separated by the $(3s^2 3p)$ $^2$P interval of the next ion from the two having the $j$-values 2 and 1. Without going into rules of correlation in detail, it may be stated that the levels of corresponding $j$-values in the $(RS)$-coupling go over to the new levels in such a way that the connecting lines do not cross. (For detail see the forthcoming paper on the spectrum of Iodine in the Proc. Roy. Soc. Lond.). Consequently, while the triplet interval may change we do not expect a change in the total $(3s^2 3p4p)$ P separation, but rather expect the former to approach the latter as a limit. This consideration enabled me to establish the $^1$P$_1$ interval from the $^3$P's.

## VII.  Location of the multiplets (3p4s←3p4p)

The most fruitful rules for location of any multiplet are the irregular doublet law, discussed in the case of $Cl_V$, and the horizontal comparison law of Saha and Majumdar.[12] The irregular doublet law is obeyed by the triplets in these spectra $(Si_I, P_{II}, S_{III}, Cl_{IV})$ in an unimpeachable manner as will be seen from Table 7. In all cases the smoothest of the differences are unbroken.

*Table 7.*

| Element | $3p.^2$ $^3$P$_2$ – $3p$ $3d.$ $^3$D$_3$ | $\triangle \nu$ | $3p$ $4s.$ $^3$P$_2$ – $3p$ $4p.$ $^3$P$_2$ | $\triangle \nu$ |
|---------|-----------------|--------|-----------------|--------|
| Si$_I$ | 54033 | | ... | |
| | | 49693 | | |
| P$_{II}$ | 103726 | | 18425 | |
| | | 38569 | | 7620 |
| S$_{III}$ | 142295 | | 26045 | |
| | | 23106 | | 7317 |
| Cl$_{IV}$ | 165401 | | 33416 | |

Application of horizontal comparison method is difficult in this case since the analysis of only two of the series $S_{IV}$, $Cl_{IV}$, $A_{IV}$, $K_{IV}$ $Ca_{IV}$, $Sc_{IV}$ and $Ti_{IV}$ are known. They are $S_{IV}$, and $Ti_{IV}$. The transition $3p^2$ $4s \leftarrow 3p^2 4p$ in the case of $S_{IV}$ gives out the line 31065, and in the transition $4s \leftarrow 4p$ in $Ti_{IV}$ the corresponding line is 48396. The law says that the centre of gravity of $4s \leftarrow 4p$ transitions of all the spectra given by Cl$_{IV}$, $A_{IV}$ .... etc. should form a linear sequence. Extrapolating in this way, the centre of gravity of $4s \leftarrow 4p$ transition of Cl$_{IV}$ comes out at about

$\nu$ 34,000 cm. $^{-1}$. This value is in good agreement with that obtained with the aid of the irregular doublet law.

The transition $4p \leftarrow 4d$ can also be located in a similar way. As this transition falls beyond the range of the data available to us we need not consider it in detail.

## VIII. Classification of the lines, and the term values of Cl$_{IV}$ spectrum

The classified lines and the approximate term values are given in Table 8 below. This table includes also the lines in the Schumann region photographed by Bowen and classified for the transition $3p \leftarrow 4s$.

*Table 8.*

| $\lambda$ | I | $\nu_{(vac)}$ | Combination | Terms | | $\triangle\nu$ |
|---|---|---|---|---|---|---|
| 463·011 | 3 | 215978 | $3p\,^3P_1-4s\,^3P_2$ | $3s^2\,3p^2\,^3P_0$ | 447123 | |
| 464·292 | 3 | 215382 | $3p\,^3P_0-4s\,^3P_1$ | | | 490 |
| 464·861 | 4 | 215118 | $3p\,^3P_2-4s\,^3P_2$ | $^3P_1$ | 446633 | |
| 465·350 | 3 | 214892 | $3p\,^3P_1-4s\,^3P_1$ | | | 848 |
| 466·132 | 3 | 214532 | $3p\,^3P_1-4s\,^3P_0$ | $^3P_2$ | 445785 | |
| 467·194 | 3 | 214044 | $3p\,^3P_2-4s\,^3P_1$ | | | |
| 2651·77 | 2 | 37699·5 | $4s\,^3P_1-4p\,^1S_0$ | $3s^2\,3p\,4s\,^3P_0$ | 232101 | |
| 2729·57 | 1 | 36624·9 | $4s\,^3P_0-4p\,^3S_1$ | | | 364 |
| 2756·86 | 2 | 36262·4 | $4s\,^3P_1-4p\,^3S_1$ | $^3P_1$ | 231737 | |
| 2841·56 | 3 | 35181·6 | $4s\,^3P_2-4p\,^3S_1$ | | | 1078 |
| 2848·36 | 2 | 35097·6 | $4s\,^1P_1-4p\,^1S_0$ | $^3P_2$ | 230659 | |
| 2898·29 | 3 | 34493·0 | $4s\,^3P_1-4p\,^3P_2$ | | | |
| 2933·86 | 1 | 34074·8 | $4s\,^3P_0-4p\,^3P_1$ | $^1P_1$ | 229135 | |
| 2965·45 | 3 | 33711·9 | $4s\,^3P_1-4p\,^3P_1$ | | | |
| 2970·42 | 2 | 33655·5 | $4s\,^1P_1-4p\,^3S_1$ | $3s^2\,3p\,4p\,^1D_2$ | 206257 | |
| 2991·67 | 4 | 33416·4 | $4s\,^3P_2-4p\,^3P_2$ | | | 346 |
| 3003·18 | 1 | 33288·4 | $4s\,^3P_1-4p\,^3P_0$ | $^3D_1$ | 202684 | |
| 3063·17 | 2 | 32636·5 | $4s\,^3P_2-4p\,^3P_1$ | | | 504 |
| 3178·76 | 1 | 32054·8 | $4s\,^3P_0-4p\,^1P_1$ | $^3D_2$ | 202338 | |
| 3134·65 | 2 | 31892·3 | $4s\,^1P_1-4p\,^3P_2$ | | | |
| 3154·39 | 0 | 31692·7 | $4s\,^3P_1-4p\,^1P_1$ | $^3D_3$ | 201834 | |
| 3213·24 | 1 | 31112·3 | $4s\,^1P_1-4p\,^3P_1$ | | | |
| 3257·73 | 1 | 30687·4 | $4s\,^1P_1-4p\,^3P_0$ | $^1P_1$ | 200045 | |
| 3265·44 | 2 | 30615·0 | $4s\,^3P_2-4pp\,^3P_1$ | | | |
| 3398·20 | 2 | 29418·9 | $4s\,^3P_0-4p\,^3D_1$ | $^3P_0$ | 198448 | |
| 3400·38 | 3 | 29400·3 | $4s\,^3P_1-4p\,^3D_2$ | | | 424 |
| 3436·44 | 3 | 29091·6 | $4s\,^1P_1-4p\,^1P_1$ | $^3P_1$ | 198024 | |
| 3440·90 | 2 | 29053·9 | $4s\,^3P_1-4p\,^3D_1$ | | | 780 |
| 3468·23 | 4 | 28834·9 | $4s\,^3P_2-4p\,^3D_3$ | $^3P_2$ | 197244 | |
| 3530·04 | 2 | 28320·2 | $4s\,^3P_2-4p\,^3D_2$ | | | |
| 3573·66 | 1 | 27974·6 | $4s\,^3P_2-4p\,^3D_1$ | $^3S_1$ | 195478 | |
| 3731·80 | 2 | 26796·3 | $4s\,^1P_1-4p\,^3D_2$ | | | |
| 3779·35 | 2 | 26452·1 | $4s\,^1P_1-4p\,^3D^1$ | $^1S_0$ | 194038 | |
| 4096·98 | 1 | 24401·4 | $4s\,^3P_2-4p\,^1D_1$ | | | |
| 4369·60 | 2 | 22879·0 | $4s\,^1P_1-4p\,^1D_2$ | | | |

The term values are obtained by assuming that corresponding terms in $3s^2\,3p^2$ and $3s^2\,4p^2$ follow Rydberg sequences. Thus the ground term $3s^2\,3p^2\,^3P$ of Cl$_{IV}$ to be 447123 cm.$^{-1}$. The ionisation potential of Cl$_{IV}$ thus comes out to be 55·17 volts. The value given by Bowen for Cl$_{IV}$ is 47·6 volts. This value is too

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low since the I.P. of $S_{IV}$, the preceding element, which must be much less than that of $Cl_{IV}$, is given by Bowen to be 47·3 volts.

In conclusion I wish to thank Prof. M. N. Saha, F.R.S., for his kind help in preparing this paper.

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## ON THE SINGULARITIES OF LAPLACE-ABEL INTEGRAL

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1. The object of this paper is to obtain certain generalizations of Polya's results[1] concerning the singularities of the Laplace-Abel integral

$$f(s) = \int_0^\infty \phi(z) \; e^{-sz} \, dz,$$

where $\phi(z)$ is an analytic function of $z$ of exponential type. Polya assumes $\phi(z)$ to be an integral function of $z$ while we take $\phi(z)$ to be an analytic function of $z$ in the angular region $|\,\text{amp } z\,| \leqq \alpha$, where $\alpha > 0$. For simplicity, we take $\alpha \leqq \dfrac{\pi}{2}$. Our first three theorems establish reciprocal relations between $\phi(z)$ and $f(z)$ similar to those established by Polya in §§ 21-22 of his memoir referred to above, and our theorem IV is a generalization of Polya's result established on page 585. Our theorem V is a generalization of a lemma of Prof. Hardy. An abstract of this paper has appeared in the Comptes Rendus, Tome 194, N° 24.

2. **Theorem I.**—*If $\phi(z)$ is an analytic function of $z$ ($=\rho e^{i\psi}$) of exponential type in the angle $|\,\psi\,| \leq \alpha$, and*

(2.1)     $\lambda(\psi) \equiv \varlimsup_{\rho \to \infty} \dfrac{\log |\,\phi\,(\rho e^{i\psi})\,|}{\rho}$ *is not negative for $|\,\psi\,| < \alpha$;*

(2.2)     $\phi(0) = 0$ ;
      *then*

(2.3)     $f(s) = \int_0^\infty \phi(z) \; e^{-sz} \, dz$

*is an analytic function of $s$ in the region lying exterior to the curve $\Sigma$ associated with $\phi(z)$ in a particular manner, and further $f(s) = O\left(\dfrac{1}{|s|^2}\right)$ in the region of its regularity.*

The integral (2.3) is absolutely and uniformly convergent in the half plane $\sigma \geq k + \delta > k$, where $\delta$ is any arbitrary positive number, and $k$ is the maximum value of $\lambda(\psi)$ in the range $-\alpha < \psi < \alpha$. Hence, $f(s)$ is an analytic function of $s$ at least in the half plane $\sigma \geq k + \delta > k$.

Now, suppose for a moment, that $s\,(=\sigma + it)$ lies in the region $\sigma > k + \delta$ and $t < -(k + \delta)$. Then

$$(2.4) \qquad \int_0^\infty \phi(z)\, e^{-sz}\, dz = \int_0^{\infty(\psi)} \phi(z)\, e^{-sz}\, dz, \qquad\qquad (0 \leq \psi \leq \alpha),$$

$$\text{since} \qquad \left| \int_0^\psi \phi\left(\rho e^{i\theta}\right) e^{-s\rho e^{i\theta}} \rho e^{i\theta} i\, d\theta \right| \longrightarrow 0 \text{ as } \rho \longrightarrow \infty.$$

Now, since

$$\int_0^{\infty(\psi)} \left| \phi(z)\, e^{-sz}\, dz \right| \leqq \int_0^\infty e^{(\lambda(\psi)+\epsilon - \sigma \cos \psi + t \sin \psi)\rho} d\rho,$$

which is uniformly convergent in the region

$$(2.5) \qquad \sigma \cos \psi - t \sin \psi \geq \lambda(\psi) + \epsilon' > \lambda(\psi), \qquad\qquad (\epsilon' > \epsilon,\ 0 \leq \psi \leq \alpha),$$

the integral on the right hand side of (2.4) is absolutely and uniformly convergent in the region (2.5), and so represents there an analytic function of $s$. The same result holds when $\psi$ lies between $-\alpha$ and $\beta$.

By the principle of analytic continuation it follows, therefore, that the function $f(s)$ defined initially by (2.3) in a certain half-plane is analytic in a much wider region, namely, the region lying exterior to the curve* $\Sigma$ which is the envelope of the lines

$$(2.6) \qquad\qquad \sigma \cos \psi - t \sin \psi = \lambda(\psi), \qquad\qquad (|\psi| \leq \alpha)$$

Now, if we can prove that the order of $f(s)$ in this region, when $s$ is sufficiently away from $\Sigma$, is $\left(\dfrac{1}{|s|^2}\right)$, then its order throughout the region (2.5) will be the same, since this region does not include the origin, which lies on or to the left of $\Sigma$.

If $s$ lies in the region of regularity of $f(s)$ and is sufficiently away from the curve $\Sigma$, then choosing the value of $\psi$ appropriately, we have

$$(2.7) \qquad f(s) = \int_0^{\infty(\psi)} \phi(z)\, e^{-sz}\, dz$$

$$= \left[ -\phi(z)\, \frac{e^{-sz}}{s} \right]_0^{\infty(\psi)} + \frac{1}{s} \int_0^{\infty(\psi)} \phi'(z)\, e^{-sz}\, dz$$

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* By the well-known properties of $\lambda(\psi)$ and the assumption (2.1), $\Sigma$ is a convex curve, the origin lying on or inside it. It is known that $\lambda'(\psi)$ possesses discontinuities of the first kind only and to these correspond straight pieces on the curve $\Sigma$.

$$= \frac{1}{s} \int\limits_{0}^{\infty(\psi)} \phi'(z)\, e^{-sz}\, dz$$

$$= \left[ \frac{-\phi'(z)\, e^{-sz}}{-s^2} \right]_{0}^{\infty(\psi)} + \frac{1}{s^2} \int\limits_{0}^{\infty(\psi)} \phi''(z)\, e^{-sz}\, dz$$

$$= O\left( \frac{1}{|s|^2} \right),$$

since $\phi(0) = 0$, and $|\phi(z) e^{-sz}|$ and $|\phi'(z) e^{-sz}|$ both $\to 0$ as $z| \to \infty$ along the radius rector $\psi$, $\phi'(z)$ being of order $e^{(k+\epsilon)\rho}$.

3.  Now we establish the converse of Theorem I.

THEOREM II.—*If $f(s)$ is analytic in the region lying exterior to the curve $\Sigma$ (defined as in theorem I), and is equal to* $O\left( \frac{1}{|s|^2} \right)$, *then there exists a function*

$$(3.1) \qquad \phi(z) = \frac{1}{2\pi i} \int\limits_{\Sigma'} f(s) e^{zs}\, ds,$$

$\Sigma'$ *being a curve to the right of and parallel to $\Sigma$ at a distance $\epsilon'$, such that $\phi(z)$ is analytic in the angle $|\psi| \leq a$, of order $e^{\{\lambda(\psi) + \epsilon\}\rho}$, and vanishes at the origin, and further*

$$f(s) = \int\limits_{0}^{\infty} \phi(z)\, e^{-sz}\, dz.$$

Now,

$$\frac{1}{2\pi i} \int\limits_{\Sigma'} f(s) e^{zs}\, ds = \frac{1}{2\pi i} \left\{ \int\limits_{L_1} f(s)\, e^{zs}\, ds + \int\limits_{L_2} f(s)\, e^{zs}\, ds \right.$$

$$\left. + \int\limits_{L_3} f(s)\, e^{zs}\, ds \right\},$$

where $L_2$ is a finite portion of the curve $\Sigma'$, and $L_1$ and $L_3$ are portions of $\Sigma'$ extending to infinity whose equations are

$$\sigma \cos a - t \sin a = \lambda(a) + \epsilon',$$

and
$$\sigma \cos a + t \sin a = \lambda(-a) + \epsilon' \text{ respectively.}$$

$$\left| \int\limits_{L_1} f(s)\, e^{zs}\, ds \right| \leqq \int\limits_{-\infty}^{a} |f(s)|\, e^{\rho(\sigma \cos \Psi - t \sin \Psi)} \sqrt{1 + \left( \frac{dt}{d\sigma} \right)^2}\, d\sigma$$

$$= \int_{-\infty}^{a} \left\{ \left| f(s) \right| \; e^{\frac{\rho \sigma}{\sin a} \left[ \cos \psi \sin a - \sin \psi \cos a \right]} \right.$$

$$e^{\frac{\rho \sin \psi}{\sin a}(\lambda(a) + \epsilon')} \sqrt{1 + \left( \frac{dt}{d\sigma} \right)^2} d\sigma$$

$$\le K \int_{-\infty}^{a} \frac{1}{|s|^2} \; e^{\frac{\rho \sigma}{\sin a} \sin(a - \psi)} \, d\sigma \, ,$$

where $a$ is finite and $K$ is a constant. The last integral will be convergent provided $\sin(a - \psi) \geqq 0$, $i.e.$, $\psi \leqq a$.

Similarly $\left| \int_{L_3} f(s) \; e^{zs} \; ds \right|$ is convergent provided $\psi > -a$.

Hence, the integral (3.1) is absolutely and uniformly convergent in the angular region $|\psi| \le a$, and so $\phi(z)$ represents an analytic function of $z$ in this angular region.

To obtain a superior limit of $|\phi(z)|$, we observe that

$$\left| \phi(z) \right| \leqq \frac{1}{2\pi} \left\{ \int_{L_1} |f(s)| \; e^{\rho(\sigma \cos \psi - t \sin \psi)} \sqrt{1 + \left( \frac{d\sigma}{dt} \right)^2} \; dt \right.$$

$$+ \int_{L_2} |f(s)| \; e^{\rho(\sigma \cos \psi - t \sin \psi)} \sqrt{1 + \left( \frac{d\sigma}{dt} \right)^2} \; dt$$

$$+ \left. \int_{L_3} |f(s)| \; e^{\rho(\sigma \cos \psi - t \sin \psi)} \sqrt{1 + \left( \frac{d\sigma}{dt} \right)^2} \; dt. \right\}$$

Now, expressions under the radical signs in each case $= O(1)$, and also $|f(s)|$ is bounded over $\Sigma'$. Thus the determination of a superior limit of $|\phi(z)|$ depends upon the maximum value of $e^{\rho(\sigma \cos \psi - t \sin \psi)}$ over the path of integration, which is the envelope of the lines (2.5). From this equation we see that given any particular value of $\psi$, say $\psi_1$, the expression $\sigma \cos \psi_1 - t \sin \psi_1$ can at most be equal to $\lambda(\psi_1) + \epsilon'$ for any point $s$ on $\Sigma'$. To prove this we observe as follows :
    The line

(3·3)                $\sigma \cos \psi_1 - t \sin \psi_1 - [\lambda(\psi_1) + \epsilon'] = 0$

is a tangent to $\Sigma'$, which lies wholly on the same side of it as the origin. Therefore, the expression on the left side of equation (3.3) is negative for all points of $\Sigma'$, except those which are common to the line (3.3), for which it is zero. Hence, the maximum value of $\sigma \cos \psi_1 - t \sin \psi_1$ on $\Sigma'$ is actually $\lambda(\psi_1) + \epsilon'$.

Consequently $|\phi(z)| \leqq e^{\rho(\lambda(\psi_1)+\epsilon'')}$ for $\rho \geqq \rho_0 (\epsilon'')$, $(\epsilon'' > \epsilon')$.

Now

(3.4) $$\phi(0) = \frac{1}{2\pi i} \int_{\Sigma'} f(s) \, ds.$$

The path of integration can be replaced by the arc of a circle of infinite radius lying to the right of $\Sigma'$; and since $|sf(s)| \longrightarrow 0$ as $|s| \longrightarrow \infty$, the value of the integral (3.4) is zero, and so $\phi(0)=0$.

It is easy to prove that for $z$ real and positive

$$\phi(z) = \frac{1}{2\pi i} \int_{\Sigma'} f(s) \, e^{zs} ds,$$

$$= \frac{1}{2\pi i} \int_{c-i\infty}^{c+i\infty} f(s) e^{zs} \, ds,$$

where $c > \lambda(0)$.

Suppose $R(\zeta) > c$. Then

$$\int_0^\infty \phi(z) e^{-\zeta z} dz = \frac{1}{2\pi i} \int_0^\infty e^{-\zeta z} \int_{c-i\infty}^{c+i\infty} e^{zs} f(s) \, ds \, dz$$

$$= \frac{1}{2\pi i} \int_{c-i\infty}^{c+i\infty} f(s) \int_0^\infty e^{-z(\zeta-s)} dz \, ds$$

(3.5) $$= \frac{1}{2\pi i} \int_{c-i\infty}^{c+i\infty} \frac{f(s) \, ds}{\zeta-s}$$

since $\int_{c-i\infty}^{c+i\infty} |\int_0^\infty |f(s) e^{-z(\zeta-s)} dz| \, ds|$ is convergent.

Now $\left|\dfrac{sf(s)}{\zeta-s}\right| \longrightarrow 0$ as $|s| \longrightarrow \infty$, and hence we can add to the contour of the integral (3.5) an arc of a circle of infinite radius lying to the right of the line $R(s) = c$. Consequently,

$$\int_0^\infty \phi(z) \, e^{-\zeta z} \, dz = f(\zeta).$$

4. In theorem II we have proved that if $f(s)$ be given satisfying certain conditions, then there is an analytic function

(4.1)
$$\phi(z) = \frac{1}{2\pi i} \int_{\Sigma'} f(s) e^{zs} ds$$

such that

(4.2)
$$f(s) = \int_0^\infty \phi(z) e^{-sz} dz,$$

Now we wish to show that $\phi(z)$ is the only analytic function of its kind which will satisfy the equation (4.2).

Suppose, if possible, that there is another analytic function $\phi_1(z)$ satisfying conditions similar to (2.1) and (2.2), which satisfies the equation (4.2). Then we will show that $\phi_1(z) \equiv \phi(z)$ as defined by (4.1).

To prove this we need only show that $\phi_1(z) = \phi(z)$ for some real and positive values of $z$.

Now, as in § 3,

$$\phi(z) = \frac{1}{2\pi i} \int_{c-i\infty}^{c+i\infty} f(s) e^{zs} ds = \frac{1}{2\pi i} \int_{c-i\infty}^{c+i\infty} e^{zs} \int_0^\infty \phi_1(t) e^{-st} dt\, ds$$

$$= \frac{1}{2\pi i} \int_{c-i\infty}^{c+i\infty} e^{zs} \left[ \int_0^R e^{-st} \phi_1(t)\, dt + \int_R^\infty e^{-st} \phi_1(t)\, dt \right] ds\, ,$$

where $R$ is arbitrary and greater than $z$, and the line $\sigma = c$ lies in the region of regularity of $f(s)$ as well as in that of $f_1(s)$ to be defined presently.

The second integral will be proved to be zero, and the first equal to $\phi_1(z)$.

Putting $u = t - R$, we get

$$\int_R^\infty e^{-st} \phi_1(t)\, dt = e^{Rs} \int_0^\infty e^{-su} \phi_1(u+R)\, du = e^{Rs} f_1(s), \text{ say.}$$

$f_1(s)$ is an analytic function of $s$ on the line $\sigma = c$ and in the half-plane lying to its right, and is of order $\left( \frac{1}{|s|} \right)$ in the region.

Now we consider

(4.3)
$$\frac{1}{2\pi i} \int_{c-i\infty}^{c+i\infty} f_1(s) e^{(z-R)s}\, ds\, .$$

Let us study the integral $\int e^{s(z-R)} f_1(s)\, ds$ extended over the rectangle whose vertices are $c - i\gamma$, $d - i\gamma$, $d + i\gamma$, an l $c + i\gamma$, $(d > c)$

$$\left| \int_{d-i\gamma}^{d+i\gamma} e^{-s(R-z)} f_1(s)\, ds \right| \leq K_1 \int_{-\gamma}^{\gamma} \frac{e^{-d(R-z)}}{\sqrt{d^2 + \gamma^2}}\, d\gamma,\ (K_1 \text{ const.})$$

and this $\longrightarrow 0$ as $d \longrightarrow \infty$, $\gamma$ remaining fixed.

Hence

$$(4.4)\quad \int_{c-i\gamma}^{c+i\gamma} e^{-s(R-z)} f_1(s)\, ds = \int_{c-i\gamma}^{\infty-i\gamma} e^{-s(R-z)} f_1(s)\, ds - \int_{c+i\gamma}^{\infty+i\gamma} e^{-s(R-z)} f_1(s)\, ds,$$

provided the last two integrals exist.

Now

$$\left| \int_{c-i\gamma}^{\infty-i\gamma} e^{-s(R-z)} f_1(s)\, ds \right| \leqq K_1 \int_{c}^{\infty} \frac{e^{-\sigma(R-z)}}{\sqrt{\sigma^2 + \gamma^2}}\, d\sigma$$

$$< \frac{K_1}{\gamma} \int_{c}^{\infty} e^{-\sigma(R-z)}\, d\sigma$$

which $\longrightarrow 0$ as $\gamma \longrightarrow \infty$.

Similarly the second member on the right hand side of (4.4) tends to 0 as $\gamma \longrightarrow \infty$.

Consequently the integral (4.3) is zero.

Now consider $\dfrac{1}{2\pi i} \displaystyle\int_{c-i\infty}^{c+i\infty} e^{zs} \int_{0}^{R} e^{-st} \phi_1(t)\, dt\, ds$.

It is equal to $\underset{\gamma \to \infty}{Lim} \dfrac{1}{2\pi i} \displaystyle\int_{0}^{R} \phi_1(t) \int_{c-i\gamma}^{c+i\gamma} e^{s(z-t)}\, ds\, dt$.

$$= \underset{\gamma \to \infty}{Lim} \frac{2i}{2\pi i} \int_{0}^{R} \phi_1(t)\, e^{c(z-t)} \frac{\sin \gamma(z-t)}{z-t}\, dt.$$

This is Fourier's integral,[2] and its value is $\phi_1(z)$, since $\phi_1(t)$ is an analytic function of $t$. That is, $\phi(z) \equiv \phi_1(z)$.

We have thus established the uniqueness of $\phi(z)$, that is we have proved the following theorem :—

THEOREM III. — *Given a function f (s) satisfying certain specified conditions, there is only one analytic function satisfying conditions (2.1) and (2.2), which can satisfy the equation (2.3).*

COROLLARY.—*Two different functions $\phi_1(z)$ and $\phi_2(z)$ cannot give rise to two functions $f_1(s)$ and $f_2(s)$ differing by a constant.*

Suppose, if possible,

$$f_1(s) - f_2(s) = K_2 = \int_0^\infty [\phi_1(z) - \phi_2(z)] e^{-sz} dz$$

$$= \int_0^\infty \phi_3(z) e^{-sz} dz, \qquad [\phi_3(z) = \phi_1(z) - \phi_2(z)].$$

By virtue of theorem I the last integral must represent a function of order $\left(\dfrac{1}{|s|^2}\right)$ which will vanish at infinity, and so $f_1(s)$ and $f_2(s)$ cannot differ by a non-zero constant.

5. THEOREM IV.—*If $\phi(z)$ satisfies (2.1) and (2.2), then f (s) is an analytic function of s outside $\Sigma$, and every tangent enveloping $\Sigma$ is a line of absolute convergence of the integral $\displaystyle\int_0^{\infty(\psi)} \phi(z) e^{-sz} dz$, and has at least one singular point of f(s) lying on it.*

Suppose, if possible, the point P (or points), at which the line $\sigma \cos \psi - t \sin \psi = \lambda(\psi)$ for any particular value of $\psi$, say $\psi_1$, touches $\Sigma$ is an ordinary point of $f(s)$. We can replace the portion of the curve $\Sigma$ in the neighbourhood of the point P (or points) by a straight piece, say L, parallel to and at a small distance $\delta$ from the tangent at P, the line L being on the same side of the tangent as the centre of curvature of the curve, so that $f(s)$ is analytic outside the curve $\Sigma'$ which is only the curve $\Sigma$ as deformed by L in the neighbourhood of P. Evidently $\Sigma'$ also is a convex curve. By virtue of the previous theorems, we have

$$\phi(z) = \frac{1}{2\pi i} \int_{\Sigma''} f(s) e^{zs} ds,$$

where $\Sigma''$ is a curve parallel to $\Sigma'$ at an arbitrarily small distance $\epsilon'$ on the side of the point P (or points), where $\epsilon' < \delta$. The equation of the portion of $\Sigma''$ corresponding to the straight piece L of $\Sigma'$ is

$$\sigma \cos \psi_1 - t \sin \psi_1 = \lambda(\psi_1) - \delta + \epsilon'.$$

Arguing as in theorem II, we see that the maximum value of $|\phi(z)|$ for $\psi=\psi_1$ depends upon the maximum value of $\sigma\cos\psi_1-t\sin\psi_1$ for points on $\Sigma''$ which can at most be equal to $\lambda(\psi_1)-\delta+\epsilon'$. That is to say,

$$(5.1) \qquad |\phi(z)| < e^{\{\lambda(\psi_1)-(\delta-\epsilon'')\}\rho}, \text{ for } \rho \geq \rho'(\epsilon''),$$

where $\epsilon''$ is a small quantity greater than $\epsilon'$ but less than $\delta$, by a proper choice of the arbitrary $\epsilon'$.

But the asymptotic equality (2.1) implies two inequalities

$$(5.2) \qquad |\phi(z)| < e^{\rho[\lambda(\psi)+\epsilon]} \text{ for every } \epsilon > 0 \text{ and } \rho \geq \rho_0(\epsilon), \text{ and}$$

$$(5.3) \qquad |\phi(z)| > e^{\rho[\lambda(\psi)-\epsilon]} \text{ for a corresponding sequence of values of } \rho$$

whose limit is infinity.

As the conditions (5.1) and (5.3) are contradictory, the point P or the points of contact of the tangent with $\Sigma$, cannot all be ordinary points of $f(s)$. This establishes our theorem.

6. Now we give a generalization of a lemma of Prof. Hardy.[3]

THEOREM V. —*A necessary and sufficient condition that $\phi(z)$ be an analytic function of $z$ in the angle $|\psi| \leq a$, vanish at the origin, and satisfy the asymptotic equality*

$$(6.1) \qquad \varlimsup_{\rho \to \infty} \frac{\log|\phi(\rho e^{i\psi})|}{\rho} = \lambda(\psi) \qquad \text{for } |\psi| \leq a,$$

*when $\lambda(\psi) \geq 0$, and is such that the envelope of the lines $\sigma\cos\psi - t\sin\psi = \lambda(\psi)$ is a convex curve, is that it should be of the form*

$$(6.2) \qquad \phi(z) = \frac{1}{2\pi i} \int_{\Sigma'} f(s)\, e^{zs}\, ds,$$

*where $f(s)$ is analytic in the region lying exterior to $\Sigma$, but not in any more extensive region of the same character, $\Sigma'$ being a curve parallel to $\Sigma$ at an arbitrarily small distance $\epsilon$ towards its right.*

That the condition is necessary follows by a successive application of theorems I, II and III, and by observing that as a consequence of theorem IV every tangent to $\Sigma$ contains at least one singular point of $f(s)$.

Everything as regards the sufficiency of the condition follows easily from the formula (6.2) excepting the asymptotic behaviour of $\phi(z)$. All that it establishes is that

$$(6.3) \qquad \varlimsup_{\rho \to \infty} \frac{\log|\phi(\rho e^{i\psi})|}{\rho} \leq \lambda(\psi).$$

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It is easy to show that the sign of inequality in (6.2) is inadmissible. Suppose for $\psi = \psi_1$, we have $\varlimsup\limits_{\rho \to \infty} \dfrac{\log |\phi\,(\rho\,e^{i\psi_1})|}{\rho} \equiv h < \lambda\,(\psi_1)$.

Then as in theorem I, $f(s)$ can be proved to be regular in the half-plane $\sigma \cos \psi_1 - t \sin \psi_1 > h$, which is greater than the half-plane

$$\sigma \cos \psi_1 - t \sin \psi_1 > \lambda\,(\psi_1).$$

But this is contrary to the hypothesis that $f(s)$ is not analytic in a more extensive region than the one lying exterior to $\Sigma$. Hence,

$$\varlimsup_{\rho \to \infty} \frac{\log |\,\phi\,(\rho\,e^{i\psi})\,|}{\rho} = \lambda\,(\psi).$$

7. In proving the foregoing theorems we have assumed (a) $\alpha \leqq \dfrac{\pi}{2}$, (b) $\phi(0)$ $= 0$ and (c) $\lambda\,(\psi)$ is not negative for any value of $\psi$. Now, so far as the study of the singularities of $f(s)$, defined initially by (2.3), is concerned all these restrictions can be removed.

(a) If $\alpha > \dfrac{\pi}{2}$, $\Sigma$ will be a closed curve and $f(s)$ will be analytic in the region lying exterior to $\Sigma$ when a cut has been drawn in it.

(b) If $\phi(0) = c \neq 0$, then

$$f(s) = \int\limits_0^\infty \left[\, c + \phi(z) - c \,\right] e^{-sz}\,dz$$

$$= \int\limits_0^\infty c\,e^{-sz}\,dz + \int\limits_0^\infty \phi_1(z)\,e^{-sz}\,dz$$

$$= \frac{c}{s} + f_1(s)\,,$$

so that the singularities of $f(s)$ can be ascertained from those of $f_1(s)$.

(c) So far as the study of the singularities of $f(s)$ is concerned, restriction (2.1) is immaterial. For, let $\lambda\,(\psi)$ be negative for some values of $\psi$. By applying the linear transformation $s = s' - (\alpha + i\beta)$ to the equation (2.3), we have

$$f[s' - (\alpha + i\beta)] = f_1(s') = \int\limits_0^\infty \phi\,(z)\,e^{(\alpha + i\beta)z}\,e^{-s'z}\,dz$$

$$= \int\limits_0^\infty \phi_1(z)\,e^{-s'z}\,dz$$

where $\alpha$, $\beta$ can be so chosen as to make $\psi_1(z)$ conform to the condition (2.1). We get a curve $\Sigma'$ in the $s'$ – plane, having the origin on or inside it, by means of which we can study the singularities of $f_1(s')$. Then the curve in the $s$– plane corresponding to $\Sigma'$ in the $s'$–plane gives the singularities of $f(s)$.

8. Now we are in a position to deduce a number of results from the foregoing theorems.

(a) *Two different functions $\phi_1(z)$ and $\phi_2(z)$ of exponential type and analytic in the region $|\psi| \leq \alpha, \alpha > \dfrac{\pi}{2}$ cannot give rise to two functions $f_1(s)$ and $f_2(s)$ which will differ by an integral function.*

Suppose

$$f_1(s) = \int_0^\infty \phi_1(z) e^{-sz} dz,$$

and

$$f_2(s) = \int_0^\infty \phi_2(z) e^{-sz} dz,$$

so that

$$f_1(s) - f_2(s) = f_3(s) = \int_0^\infty \phi_3(z) e^{-sz} dz,$$

where

$$\phi_3(z) \equiv \phi_1(z) - \phi_2(z).$$

Now $f_3(s)$ is analytic outside a closed curve $\Sigma$ when a cut has been drawn in the $s$-plane and its order is $\left(\dfrac{1}{|s|}\right)$ in the region of its regularity.

But by assumption $f_3(s)$ is an integral function and so the cut disappears. By virtue of the order of $f_3(s)$ we find $f_3(s) \equiv 0$. This means that $\phi_1(z)$ and $\phi_2(z)$ are identical functions, which contradicts our hypothesis.

(b) *If $f_1(s)$ and $f_2(s)$ be defined by*

$$f_1(s) = \int_0^\infty \phi(a + z) e^{-sz} dz, \text{ and}$$

$$f_2(s) = \int_0^\infty \phi(b + z) e^{-sz} dz,$$

*where $\phi(z)$ is an analytic function of $z$ in the region $|\psi| \leq \alpha$, and the points $a$ and $b$ lie in this region, then $f_1(s)$ and $f_2(s)$ have the same line of absolute convergence, and the same singularities.*

To prove this we need only observe that

$$f_1(s) = \int_0^\infty \phi(z+a) e^{-sz} dz = e^{as} \int_a^\infty \phi(u) e^{-su} du,$$

and

$$f_2(s) = \int_0^\infty \phi(z+b) e^{-sz} dz = e^{bs} \int_b^\infty \phi(u) e^{-su} du,$$

so that $e^{-as} f_1(s) - e^{-bs} f_2(s) = \int_b^a \phi(u) e^{-su} du = $ an integral function of $s$.

The above is a generalization of a result due to Polya.[*]

(c)   *Suppose the functions $f_1(s)$ and $f_2(s)$ are defined by the series*

$$f_1(s) = \sum_0^\infty \phi(a+n) e^{-sn} \text{ and } f_2(s) = \sum_0^\infty \phi(b+n) e^{-sn}$$

*respectively, where $\phi(z)$ is an analytic function of $z$ for $R(z) \geqq 0$ and is of order $(e^{k\rho})$, $0 \leqq k < \pi$, and where $a$ and $b$ are constants such that $R(a)$ and $R(b)$ both $\geqq 0$. Then $f_1(s)$ and $f_2(s)$ have the same line of absolute convergence, and the same singularities.*

$$\sum_{\nu=1}^{\nu=n} \phi(a+\nu) e^{-s(a+\nu)} = \frac{1}{2\pi i} \int_C \frac{\phi(a+z) e^{-s(a+z)}}{e^{2\pi i z} - 1} dz,$$

where $C$ is the contour made of the line $R(z) = \frac{1}{2}$ and the arc of the circle $|z| = n + \frac{1}{2}$ lying to the right of the line $R(z) = \frac{1}{2}$.

By means of the above formula we can easily prove that for certain values of $s$

$$\sum_1^\infty \phi(a+\nu) e^{-s(a+\nu)} = e^{-as} \int_{\frac{1}{2}}^{\frac{1}{2}-i\infty} \frac{\phi(a+z) e^{-sz}}{e^{2\pi i z} - 1} dz - e^{-as} \int_{\frac{1}{2}}^{\frac{1}{2}+i\infty} \frac{\phi(a+z) e^{-sz}}{e^{2\pi i z} - 1} dz$$

$$= e^{-as} \int_{\frac{1}{2}}^\infty \phi(a+z) e^{-sz} dz$$

$$+ e^{-as} \int_{\frac{1}{2}}^{\frac{1}{2}+i\infty} \frac{\phi(a+z) e^{-sz}}{e^{-2\pi i z} - 1} dz + e^{-as} \int_{\frac{1}{2}}^{\frac{1}{2}-i\infty} \frac{\phi(a+z) e^{-sz}}{e^{2\pi i z} - 1} dz$$

Now, it is easy to see that the second integral is absolutely and uniformly convergent over the region $2\pi - k \geqq t + \delta > t$, $\sigma$ bounded, and that the third integral over the region

$$t \gtreqless -(2\pi - k) + \delta > -(2\pi - k).$$

Hence, both the integrals represent an analytic function of $s$ in any finite part of the strip $|t| \leq \pi$.

Thus, by the principle of analytic continuation

$$e^{-as} f_1(s) = e^{-as} \sum_0^\infty \phi(a+n) e^{-sn} = g_1(s) + e^{-as} \int_0^\infty \phi(a+z) e^{-sz} dz,$$

and

$$e^{-bs} f_2(s) = e^{-bs} \sum_0^\infty \phi(b+n) e^{-sn} = g_2(s) + e^{-bs} \int_0^\infty \phi(b+z) e^{-sz} dz,$$

where $g_1(s)$ and $g_2(s)$ are analytic functions of $s$ in any finite part of the strip $|t| \leq \pi$.

Now the proposition follows by an application of the preceding result (b). This gives an extension of another result due to Polya.[5]

(d) Theorem IV enables us to study the singularities of the Dirichlet's series

$$\sum_1^\infty \phi(\log n) \, n^{-s+1}.$$ Proceeding as in (c) above it can be established that

$$\sum_1^\infty \phi(\log n) \, n^{-s+1} = G(s) + \int_0^\infty \phi(z) \, e^{-sz} dz,$$

where $G(s)$ is an integral function of $s$.

Thus the singularities of the Dirichlet's series and the integral $\int_0^\infty \phi(z) e^{-sz} dz$ are identical.

(e) *If $\phi(z)$ is an analytic function of $z$ in the half-plane $R(z) \geq 0$ and is of order* $e^{\kappa \rho}$, $0 \leq k < \pi$, *then*

$$\overline{\lim_{n \to \infty}} \, |\phi(n)|^{\frac{1}{n}} = \overline{\lim_{\rho \to \infty}} \, |\phi(\rho)|^{\frac{1}{\rho}},$$

*where $n$ has the integral values $1, 2, 3, 4 \ldots$ and $\rho$ passes through all the positive values.*

Let $\overline{\lim_{n \to \infty}} \, |\phi(n)|^{\frac{1}{n}} = e^\alpha$ and $\overline{\lim_{\rho \to \infty}} \, |\phi(\rho)|^{\frac{1}{\rho}} = e^{\lambda(0)}$.

Now, let us consider $F(s)$ defined by

$$F(s) = \sum_0^\infty \phi(\nu) \, e^{-s\nu}.$$

By a well-known formula this power series in $e^{-s}$ has $\sigma = \alpha$ for its line of absolute convergence, and on this line at least one singularity of F $(s)$ lies.

Also, proceeding as in $(c)$, we get the relation

$$F(s) = g(s) + \int_{0}^{\infty} \phi(z) e^{-sz} dz$$

$$= g(s) + f(s) ,$$

where $g(s)$ is an analytic function of $s$ in any finite part of the strip $|t| \leq \pi$, and $f(s)$ is analytic outside a convex curve $\Sigma$, which on account of the restriction on $k$ lies entirely in the strip $|t| \leq \pi$. That is, all the finite singularites of $F(s)$ in the strip $|t| \leq \pi$ are identical with those of $f(s)$.

Now by virtue of theorem IV, the line of absolute convergence of the integral $\int_{0}^{\infty} \phi(z) e^{-sz} dz$, viz. $\sigma = \lambda(0)$, has at least one singularity of $f(s)$ lying on it, and $f(s)$ is analytic to the right of this line. Hence the lines $\sigma = \lambda(0)$ and $\sigma = \alpha$ are identical, that is $\alpha = \lambda(0)$.

This proposition is a generalization of another result due to Polya.[6]

### References.

[1] G. Polya, *Math. Zeitschrift*, **92**, 606, 1928.

[2] C. Jourdan, *Cours d' Analyse*, 3rd edition, Vol. 2, p. 277, 1913.

[3] Hardy, *Acta Math.*, **42**, 333.

[4] G. Polya, *Math. Zeitschrift*, **29**, 590, 1929.

[5] *Loc. cit.*, p. 608.

[6] *Loc. cit.*, p. 606.

# SOME NEW ULTRA-VIOLET SOLUTION LIGHT FILTERS.

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It is highly essential in photochemical reactions to have a monochromatic source of light to study the effect of various wavelengths. We have already investigated some of the light filters and their visible transmissions.[1] In this paper the use of certain solutions for the transmission of purely ultraviolet radiations is very briefly discussed.

It is well known that the addition of nickel oxide makes a glass very suitable for the transmission of ultraviolet rays and cuts off visible and infra-red radiations.[2] Nickel chloride, nickel nitrate, nickel sulphate $NiSO_4 + 7H_2O$ and nickel acetate have been examined[3] in search of a substance for the complete absorption of infrared radiations.[4] No quantitative investigations seem to have been made concerning the visible and ultraviolet transmission of these salts. Moreover, the variation in absorption with change in concentration is unknown. I have studied nickel nitrate singly, as well as in combination with potassium dichromate, picric acid and cobalt chloride, from all these considerations. Some of my results are recorded below.

Experimental arrangement for the determination of absorption was the same as described in previous papers. For visible, point-o-light and Nutting's spectrophotometer and for ultraviolet copper arc and quartz spectrograph were used. The results are given in the following tables where $\lambda$ = wavelength in Å units; T=transmission; $l$=thickness of the solution in quartz cell; $d$=density reading and $e$=extinction coefficient.

## Measurements in the Visible

*Table 1.*—Ni $(NO_3)_2$. 4·16M.   $l=1$ cm.

| λ | $d$ | % T | λ | $d$ | % T |
|---|-----|-----|---|-----|-----|
| 4400 | ∞ | 0 | 5200 | 1·17 | 6·7 |
| 4500 | 3·20 | 0·063 | 5600 | 1·25 | 5·6 |
| 4600 | 2·45 | 0·35 | 5800 | 1·95 | 1·1 |
| 4800 | 1·30 | 5·0 | 5900 | 2·65 | 0·22 |
| 5000 | 1·10 | 7·9 | 6100 | ∞ | 0 |

*Table 2.*—Ni $(NO_3)_2$ 2·08M.   $l=1$ cm.

| λ | $d$ | % T | λ | $d$ | % T |
|---|-----|-----|---|-----|-----|
| 4300 | ∞ | 0 | 5600 | 0·60 | 25·1 |
| 4600 | 1·20 | 6·3 | 5800 | 0·96 | 10·9 |
| 4800 | 0.57 | 26·9 | 6200 | 3·0 | 0·1 |
| 5000 | 0·52 | 30·2 | 6300 | 3·8 | 0·016 |
| 5200 | 0·55 | 28·1 | 6400 | ∞ | 0 |

*Table 3.*—Ni $(NO_3)_2$ 1·04M.   $l=1$ cm.

| λ | $d$ | % T | λ | $d$ | % T |
|---|-----|-----|---|-----|-----|
| 4400 | 0·82 | 15·1 | 5800 | 0·47 | 33·8 |
| 4800 | 0·30 | 50 | 6000 | 0·83 | 14·7 |
| 5000 | 0·25 | 56·2 | 6400 | 1·90 | 1·26 |
| 5400 | 0·27 | 53·7 | 7000 | 2·45 | 0·35 |

*Table 4.*—Ni $(NO_3)_2$ 0·208M.   $l=1$ cm.

| λ | d | % T | λ | d | % T |
|---|---|-----|---|---|-----|
| 4400 | 0·16 | 69·1 | 5800 | 0·09 | 81·5 |
| 4800 | 0·06 | 87·1 | 6000 | 0·016 | 69·2 |
| 5000 | 0·04 | 91·2 | 6400 | 0·36 | 43·6 |
| 5200 | 0·05 | 89·1 | 7000 | 0·45 | 35·5 |

*Table 5.*—$K_2 Cr_2 O_7$ 0·513M.   $l=1$ cm.

| λ | d | % T | λ | d | % T |
|---|---|-----|---|---|-----|
| 5350 | ∞ | 0 | 5700 | 0·20 | 63·0 |
| 5400 | 2·8 | 0·16 | 5800 | 0·14 | 72·4 |
| 5500 | 1·06 | 8·7 | 5900 | 0·04 | 91·2 |
| 5600 | 0·40 | 39·8 | 6000 | 0·04 | 91·2 |

*Table 6.*—$K_2 Cr_2 O_7$ 0·256M.   $l=1$ cm.

| λ | d | % T | λ | d | % T |
|---|---|-----|---|---|-----|
| 5200 | ∞ | 0 | 5500 | 0·52 | 30·2 |
| 5300 | 3·40 | 0·039 | 5600 | 0·20 | 63·0 |
| 5400 | 1·32 | 4·78 | 5800 | 0·02 | 95·5 |

*Table 7.*—$K_2 Cr_2 O_7$ 0·0513M.   $l=1$ cm.

| λ | d | % T | λ | d | % T |
|---|---|-----|---|---|-----|
| 5000 | ∞ | 0 | 5500 | 0·10 | 79·4 |
| 5100 | 2·76 | 0·17 | 5800 | 0·04 | 91·2 |
| 5200 | 1·40 | 3·9 | 6000 | 0·02 | 95·5 |
| 5400 | 0·25 | 56·2 | 6200 | ... | ... |

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*Table 8.*—$CoCl_2$ 3·66 M.      $l = 1$ cm.

| $\lambda$ | $d$ | %T | $\lambda$ | $d$ | %T |
|---|---|---|---|---|---|
| 4000 to 7100 | $\infty$ | 0 | 7300 | 1·60 | 2·5 |
|  | $\infty$ | 0 | 7400 | 1·20 | 6·3 |
| 7200 | 3·01 | 0·01 | 7600 | 0·95 | 11·2 |

*Table 9.*—$CoCl_2$ 1·83 M.   $l = 1$ cm.

| $\lambda$ | $d$ | %T | $\lambda$ | $d$ | %T |
|---|---|---|---|---|---|
| 4300 | 2·25 | 0·56 | 5800 | 1·70 | 1·9 |
| 4400 | 3·75 | 0·017 | 6000 | 1·05 | 8·9 |
| 4500 to 5500 | $\infty$ | 0 | 6200 | 0·85 | 14·1 |
|  | $\infty$ | 0 | 6600 | 0·82 | 15·1 |
| 5700 | 2·65 | 0·22 | 7200 | 0·50 | 31·6 |

*Table 10.*—$CoCl_2$ 0·915 M.      $l = 1$ cm.

| $\lambda$ | $d$ | %T | $\lambda$ | $d$ | %T |
|---|---|---|---|---|---|
| 4200 | 0·93 | 11·7 | 5400 | 3·75 | 0·017 |
| 4400 | 1·6 | 2·5 | 5800 | 0·73 | 18·6 |
| 4600 | 3·15 | 0·07 | 6200 | 0·46 | 34·6 |
| 4900 to 5200 | $\infty$ | 0 | 6400 | 0·42 | 38·0 |
|  | $\infty$ | 0 | 7000 | 0 32 | 47·8 |

*Table 11.*—$CoCl_2$ 0·183 M.      $l = 1$ cm.

| $\lambda$ | $d$ | %T | $\lambda$ | $d$ | %T |
|---|---|---|---|---|---|
| 4200 | 0·25 | 56·0 | 5600 | 0·28 | 52·4 |
| 4400 | 0·35 | 44·6 | 5800 | 0·10 | 79·4 |
| 4600 | 0·59 | 25·7 | 6000 | 0·08 | 83·1 |
| 4800 | 0·69 | 20·4 | 6600 | 0·07 | 85·1 |
| 5400 | 0·55 | 28·1 | 7000 | 0·05 | 89·1 |

*Table 12.*—Ni $(NO_3)_2$ 4·16 M + $K_2Cr_2O_7$ 0·513M. each in one centimeter cell.

| λ | $d$ | %T | λ | $d$ | %T |
|---|---|---|---|---|---|
| 5400 | ∞ | 0 | 5800 | 2·10 | 0·79 |
| 5500 | 2·30 | 0·50 | 5900 | 2·70 | 0·20 |
| 5600 | 1·70 | 1·99 | 6000 | 4·5 | 0·003 |
| 5700 | 1·70 | 1·99 | 6100 | ∞ | 0 |

*Table 13.*— Ni $(NO_3)_2$ 4·16 M + $K_2Cr_2O_7$ 0·256 M each in 1 cm. cell.

| λ | $d$ | %T | λ | $d$ | %T |
|---|---|---|---|---|---|
| 5300 | ∞ | 0 | 5800 | 2·0 | 1·0 |
| 5400 | 2·60 | 0·25 | 5900 | 2·65 | 0·22 |
| 5500 | 1·75 | 1·7 | 6000 | 4·5 | 0·003 |
| 5600 | 1·45 | 3·5 | 6100 | ∞ | 0 |

*Table 14.*—$CoCl_2$ 3·66 M + $K_2Cr_2O_7$ of any concentration each in 1 cm. cell. Transmits same as $CoCl_2$3·66M.

*Table 15.*—$CoCl_2$ 1·83 M +$K_2Cr_2O_7$ 0·513 M. each in 1 cm. cell.

| λ | $d$ | %T | λ | $d$ | %T |
|---|---|---|---|---|---|
| 5500 | ∞ | 0 | 6000 | 1·10 | 7·9 |
| 5700 | 2·85 | 0·14 | 9200 | 0·85 | 14·0 |
| 5800 | 1·84 | 1·4 | 7200 | 0·50 | 31·6 |

*Table 16.*—Ni $(NO_3)_2$ 2·08 M + $K_2Cr_2O_7$ 0·513 M. each in 1 cm. cell.

| λ | $d$ | %T | λ | $d$ | %T |
|---|---|---|---|---|---|
| 5350 | ∞ | 0 | 6000 | 1·70 | 1·99 |
| 5400 | 3·40 | 0·025 | 6200 | 3·0 | 0·10 |
| 5600 | 1·70 | 1·99 | 6300 | 3·7 | 0·0199 |
| 5800 | 1·05 | 8·9 | 6400 | ∞ | 0 |

*Table 17.*—Ni (NO$_3$)$_2$ 4·16 M + CoCl$_2$ 3·66 M. each in 1 cm. cell.
Transmits no visible.

*Table 18.*—Ni (NO$_3$)$_2$ 2·08 M + CoCl$_2$ 3·66 M. each in 1 cm. cell.
Transmits no visible.

| 19 Ni (NO$_3$)$_2$ 4·16 M.+ CoCl$_2$ 1·83 M. each in 1 cm. cell. | | | 20 Ni (NO$_3$)$_2$ 2·08 M + CoCl$_2$ 1·83 M. each in 1 cm. cell. | | |
|---|---|---|---|---|---|
| λ | $d$ | %T | λ | $d$ | %T |
| 5606 | ∞ | 0 | 5600 | ∞ | 0 |
| 5700 | 4·4 | 0·0025 | 5800 | 2·70 | 0·2 |
| 5800 | 3·70 | 0·02 | 6000 | 2·75 | 0·17 |
| 5900 | 4·0 | 0·01 | 6200 | 3·90 | 0·012 |
| 6000 | ∞ | 0 | 6300 | ∞ | 0 |

## Infra-red Transmission (4)

*Table 1.*—Ni (NO$_3$)$_2$. 10 gms. in 100 c. cs. of water $l$=1 cm.

| λ | % T | λ | % T |
|---|---|---|---|
| 6000 | 42 | 10000 | 33 |
| 7000 | 11 | 11000 | 15 |
| 8000 | 50 | 12000 | 8 |
| 9000 | 64 | 13000 | 4 |

*Table 2.*—Ni (NO$_3$)$_2$.   (*a*) 4·16 M.   (*b*) 2·08 M.   $l$= 1 cm.
calculated from (1) assuming Beer's law absorption.

| λ | % T (*a*) | % T (*b*) | λ | % T (*a*) | % T (*b*) |
|---|---|---|---|---|---|
| 6000 | 0·29 | 5·4 | 10000 | 0·037 | 1·99 |
| 7000 | 0 | 0·04 | 11000 | 0 | 0·12 |
| 8000 | 0·67 | 8·3 | 12000 | 0 | 0·026 |
| 9000 | 3·98 | 10·2 | 13000 | 0 | 0 |

## Ultra-violet and Visible Transmission (photographically)

| Salt | Time of exposure | Visible | Ultra-violet |
|---|---|---|---|
| (1) $K_2 Cr_2 O_7$ any concentration >00.005 M. ... | 4 hours. | — | Nil |
| (2) Ni $(NO_3)_2$ 4·16 M. ... | 5 ,, | 4415—6100A° | 3327—3527A° |
| (3) Ni $(NO_3)_2$ 2·08 M. .. | 2 ,, | 4300—6400A° | 3307—3598A° |
| (4) Ni $(NO_3)_2$ 2·08M+ $CoCl_2$ 1·83 M. ... | 4 ,, | 5600—6300A° | 3507—3598A° |
| (5) Ni $(NO_3)_2$ 4·16 M + $CoCl_2$ 3·66 M. ... | 4 ,, | Nil | 3420—3527 (Faint) |
| (6) Ni $(NO_3)_2$ 4·16M + $CoCl_2$ 1·83 M. ... | 4 ,, | 5600—6000A° | 3337—3527A° |
| (7) Corning violet-ultra ... | 4 ,, | Nil | 3248—3825A° |
| (8) Ni $(NO)_3)_2$ 2·08 M + $CoCl_2$ 3·66 M. ... | ... | Nil | 3307—3598A° |
| (9) $CoCl_2$ 3·66M. ... | 4 ,, | 7100—7600A° | 2618—4063A° |
| (10) $CoCl_2$ 3·66 M+ $K_2Cr_2O_7$ 0·00154 M. ... | 5 ,, | 7100—7600A° | 4023—4063 and 3290—2961 A° |

It will be observed that the filters Nos. 5 to 10 are suitable for ultraviolet transmission. The intensity of filter No. 5 is extremely low. Filter No. 6, although it transmits little of visible in addition to the same ultraviolet as filter No. 8 its transmission is practically the same. Corning violet is comparable with filter No. 8 the ultraviolet range being much smaller than the corning filter. Filter No. 9 transmits highly in the ultraviolet in addition to far in the red. (7100—7600)°. So far photochemical reactions are concerned this transmission on the longer wavelength side has got practically no effect and hence the filter is useful for ultraviolet work.

A. K. Bhattacharya has used my filters and determined the velocity of the photochemical decomposition of ferric thiocyanate and studied the reaction between potassium oxalate and bromine, using quartz mercury vapour lamp as light source. His results of the velocity constants are recorded below.

|  | Ferrithiocyanate $K_1$ | Potassium oxalate and bromine. $K_1$ |
|---|---|---|
| (7) Corning glass. ultraviolet ... | 0·000987. | 0·0139 |
| (8) Ni $(NO_3)_2$ 2.08M + $CoCl_2$ 3·66 M ... | 0·00107 | 0·0137 |
| (9) $CoCl_2$ 3·66M ... ... ... | 0·00176 | 0·0183 |

These results clearly show that the filter No. 9 is decidedly superior to filter Nos. 7 and 8, both of which are equally good. In view of the fact the range of transmission of filter No. 8 is much shorter than the corning glass the filter is

therefore decidedly better than No. 7. I therefore recommend my following two solution light filters for ultraviolet work.

|                                                   |        |        | Transmits |
| --- | --- | --- | --- |
| Filter (8) Cobalt chloride 3·66 M.   ... | ... | ... 3307—3598 Å |
|               Nickel  nitrate 2·08 M.   ... | ... | ... |
| Filter (9) Cobalt chloride 3·66 M.   ... | ... | ... 2618—4063 Å and |
|                                                   |        |        | 7100—7600 Å |

The filter No. 10 is also very useful as it transmits lower ultraviolet, the range at the same time being much shorter than cobalt chloride alone. This filter has not been worked out as yet and the further work is in progress.

In the conclusion I wish to express my indebtedness to Prof. N. R. Dhar for his constant guidance and help in the course of this work. My thanks are also due to A. K. Bhattacharya for allowing me to use his results.

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# AGEING OF HYDROSOLS OF FERRIC PHOSPHATE AND VANADIUM PENTOXIDE

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In the course of the study of viscosity of ferric phosphate sol at various pressures the authors observed[1] that a fairly pure sample of ferric phosphate when heated sets to a firm jelly and again passed into the sol condition when cooled. This behaviour was also observed with other sols like those of $Al(OH)_3$ prepared by hydrolysing aluminium acetate and ferric arsenate. This observation appears interesting and in order to throw light on the mechanism of such change the viscosity, electrical conductivity and the stability of ferric phosphate sol at various temperatures were measured.

Ferric phosphate sol was obtained by the interaction of $FeCl_3$ and $KH_2PO_4$ and the sol thus prepared was allowed to dialyse for five days to free it from chloride ions. It was not possible to free the sol completely from the chloride ions because the sol at this stage becomes very viscous and finally sets to a firm jelly. The sol thus prepared was of a deep red colour and contained 32·1 grams of ferric phosphate and 0·4328 grams of chlorine ion per litre of the sol.

Our results on the measurement of the viscosity of the sol at temperatures 30°, 40°, 50° and 60°C show that the viscosity first decreases and then increases remarkably with increasing temperature. The electrical conductivity continuously increases, the percentage of increase or the temperature coefficient of the electrical conductivity is greater than that for an electrolyte at these temperatures. The stability of the sol and the ratio of the precipitating concentration of KCl to that of $BaCl_2$ rapidly diminishes showing that the electric charge on the colloid particles decreases.[2]

It was found that the sol very quickly shows a change in the properties studied in this paper at the higher temperatures with time. We have, therefore, investigated the changes in these properties at the temperatures 40°, 50° and 60°C with time.

Our experimental results show that within 6 hours of observation the changes were more pronounced at higher temperatures than at lower ones. At 40°, 50° and 60°C both the viscosity and the electrical conductivity continue to increase and the stability and the ratio of the precipitating concentration of KCl to $BaCl_2$ are slightly decreased. At 60°C the changes in the viscosity of the sol was so rapid that it sets to a firm gel after five hours.

After keeping the sol at the higher temperature for six hours it was brought to a bath maintained at 20°C and the viscosity, electrical conductivity and the stability towards KCl and BaCl₂ were measured for 48 hours. It was found that the sols treated at higher temperatures showed greater viscosity and electrical conductivity and was less stable than the sol kept at ordinary room temperature and this was more in magnitude for the sols treated at a higher temperature than that at a lower one. As the sols were kept at 20°C, the viscosity and the electrical conductivity diminished and the stability and the electric charge on the colloid particles appreciably increased with time tending to reach the condition of the sol which is kept only at the room temperature. It was found that the viscosity and the electrical conductivity were greater and the stability (and hence the electric charge) remained less than the sol kept at the room temperature even after keeping the sols at 20°C for five days. When these viscous sols were highly agitated by shaking, their viscosities decreased appreciably but there was no change in their electrical conductivities and in their stability.

These results obtained with a sol or ferric phosphate which is positively charged, show that at higher temperatures the adsorbed electrolyte that stabilises the sol is given out gradually making the sol less stable, more conducting and more viscous. It is apparent that this behaviour is expected to be more marked at higher temperatures than at lower ones. When these sols, rendered more viscous and electrically conducting and less stable at a higher temperature, are brought to a lower temperature, the electrolyte given out at higher temperature, is again taken up gradually by the colloid particles making the sol less viscous and conducting and more stable with time. As the colloid kept at a higher temperature ages and hence loses the adsorptive capacity more quickly than that kept at the room temperature, it is easy to see that for the former sols the viscosity, conductivity and the electric charge on colloid particles cannot reach the values as those for the latter one.

It is generally believed by the colloid chemists that a highly viscous sol is essentially connected with the high hydration of colloid particles. We have, therefore, to conclude from this that the colloid particles of ferric phosphate becomes more hydrated at higher temperatures, so much so that 3·2 per cent of FePO₄ is associated with the rest of the water of the sol and the sol is converted into a gel at 60°C. It is, however, not possible to understand how a colloid particle, which loses its adsorptive capacity at higher temperatures is hydrated to a greater extent than a colloid particle which has high adsorptive power and is less hydrated at a lower temperature. We are, therefore, of opinion as we have expressed in our previous communication[1] that in the case of so-called highly viscous sols all that we measure is the structural flow and not the true viscosity. As the ferric phosphate colloid particle loses the stabilising electrolyte, the electrical charge is decreased and the chances for the formation of a structure in the sol is increased. This structure is formed as we have already pointed out in our publications in this

subject from a 'loose crystallographic force.' Our views are further strengthened by our observation that a sol of ferric phosphate kept at a temperature of 50°C becomes more rapidly viscous when the sol is sewn with an already formed gel of ferric phosphate of the same concentration as the sol. This sowing does not effect the electrical conductivity and the stability. That this structure is maintained even when the sol is brought to a lower temperature can be shown by the fact that the viscosity can be appreciably diminished by agitating the sol by shaking and the phenomenon is alike to that observed by us during the course of gelation of sols of agar and gelatin read before the academy and nomenclatured as 'hysterisis in in the process of gelation.'[3]

Our results on the ferric phosphate sol lead to another important issue, *viz.*, the effect of time on this sol is dependent on the previous treatment that the sol has undergone. Thus the sol prepared at lower temperatures when brought to a higher one it shows an increase in viscosity and the electrical conductivity and a decrease in stability, whilst the very sol shows a different behaviour when brought from a higher temperature to a lower one.

It may be of interest that D. N. Chakravarti[4] has studied the influence of time for over three months on the viscosity and the electrical conductivity of ferric phosphate sol at ordinary temperature of the room. These results show that the viscosity decreases and the electrical conductivity increases with time. We are of opinion that in view of the fact that the greater time was allowed by this investigator in the ageing of the sol, sufficient aggregation of the colloid particles occurred with the consequent decrease in the viscosity and increase in the electrical conductivity.

We shall now report an abstract of our results obtained with vanadium pentoxide sol on the similar experimental lines as followed in the case of ferric phosphate sol. This sol required investigation as it has been proved by one of the authors of this paper in collaboration with Professor N. R. Dhar[5] that it belonged to a separate class of colloids because it contains some of the substance in the molecular condition according to the scheme

$$(V_2O_5)_x(H_2O)_y \rightleftharpoons (HVO_3)_x \rightleftharpoons HVO_3$$

Colloid                aggregated acid        Simple vanadic acid
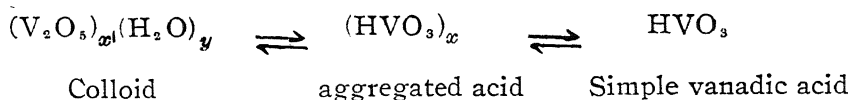
Vanadium pentoxide sol was prepared by precipitating vanadic acid from ammonium vanadate by the action of concentrated HCl and then washing the precipitate till it has a tendency to pass to a colloidal state. The whole of the precipitate is now shaken with distilled water and the sol thus formed is allowed to dialyse till it was free from HCl.

It was found that the viscosities of vanadium pentoxide sol diminish more rapidly than those of water on inceasing the temperature. The electrical conductivity also increased remarkably. Though the amounts of KCl and $BaCl_2$ necessary to

F. 4

coagulate the sol diminished but the ratio of their precipitating concentrations increased with the increasing temperature showing an increase in the electric charge on the colloid particles.

Influence of time on the viscosity, electrical conductivity and stability of vanadium pentoxide sol at 40°, 50° and 60° C were also measured and it was found that in all cases the viscosity diminishes and the electrical conductivity and the electrical charge on the colloid particles gradually increase, the effect being more pronounced at higher temperatures than that at a lower one. This is most probably due to the fact that more of molecular vanadic acid is formed at the expense of the colloidal aggregates of the sol and this therefore makes the sol less viscous, more conducting and more stable.

It must be recalled here that silicic acid sol which belongs to the same class of colloids as that of vanadium pentoxide rapidly increases in viscosity and finally sets to a firm gel when heated.

It will be of interest to note in this paper that a diminution of the electric charge on a colloid particle increases the viscosity of a sol and *vice versa* and it is in agreement with the conclusion of Dhar.[6]   Smoluchowski,[7] on the other hand, concludes that the viscosity of a sol should increase with the increasing charge on the colloidal particle.

We are of opinion that the rate of flow of a sol under a definite pressure should diminish as the electric charge on a colloid particle decreases. We have shown elsewhere that in the flow for the so-called highly viscous sols the simple rule of viscosity, *viz.*, rate of flow is directly proportional to the pressure causing the flow, is not applicable. We have concluded in the same paper that some kind of structure is formed amongst the colloid particles. Smoluchowski has not taken this into account and hence his conclusion has no experimental support. Again the effect of the variation in the hydration of the colloid particles due to a change in the electrical charge on the colloid particles may change the total effective volume of the colloid more prominently and thence the viscosity than the electroviscous effect of Smoluchowski.

In conclusion the authors desire to express their indebtedness to Professor N. R. Dhar in giving his valuable suggestions in the progress of this work.

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# CHEMICAL EXAMINATION OF THE SEEDS OF THEVETIA NERIIFOLIA (JUSS), PART I.

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Thevetia neriifolia (N. O. Apocynaceæ) or yellow oleander as it is known in English, *pila-kaner* in Hindustani and *kalki-phul* in Bengali is a common garden plant in India generally cultivated for its bright yellow ornamental flowers and clusters of long deep pointed leaves. The plant scarcely attains a height of more than fifteen feet and is covered with a smooth greenish grey bark which, when cut or broken, yields a copious milky secretion. The fruit has got the external appearance of a pyramid on a hemispherical base and is often nearly two inches in length, but after the fleshy portion is removed it yields a hard brown triangular nut, with a deep groove or cleft in the middle along which the nut can be easily broken to yield two complete pieces of white flattened kernels covered with a thin onion coloured membrane. The kernels are extremely bitter.

The whole plant is poisonous, particularly so is the fruit, which has been responsible for many suicides in Bengal and many cases of cattle poisoning in the Bombay Presidency. On account of its poisonous nature, *i.e.*, to say its intense physiological reactivity, various parts of the plant have from time to time been used as remedies for various ailments, *e.g.*, the bark as an emetic and antiperiodic and in larger doses drastic purgative; the juice as vesicant; the fruit as a powerful emetic; the root as an antipyretic and so on. For detailed information reference may be made to Dymock's Pharmacographia Indica, Vol. 2, pp. 406—410. The seeds

contain an active principle which has been isolated in the crude form by various authors and has been found to be a strong cardiac poison producing death in large doses by asphyxia and paralysis of the heart with great lowering of the body temperature. It is a strong irritant for the skin, producing a mass of minute eruptions resembling eczema. In ordinary doses it produces convulsions.

De Vrij[1] discovered in the seeds a glucoside (which apparently he could not obtain in a pure form since no melting point or formula is given), which was closely studied by Blas. Blas and Husemann[2] tested the action of the glucoside on animal and found it to have the same effect on frogs as digitalin. Apart from the isolation of thevetin, referred to above, De Vrij also found that the kernels of the seeds give with benzine 57 per cent of a limpid oil. Bhattacharya and Ayyar[3] also obtained with light petroleum a yellow oil, the oil content being 57 per cent. In addition to thevetin the existence of a second poisonous principle in the seed was proved by Warden,[4] who isolated an amorphous sticky resin from the mother liquor from which thevetin had been extracted. Warden also extracted a blue principle from the seeds of Thevetia neriifolia in the form of a dark amorphous insoluble powder by the action of concentrated hydrochloric acid on the purified aqueous extracts of the oil free kernels. This blue substance which he named 'thevetin-blue,' was thought by the author to be pseudo-indican.

Blas[5] gave the formula $C_{54}H_{84}O_{24} + 3 H_2O$ to thevetin, m. p. 170°C., the active principle and $C_{48} H_{70} O_{10} + 2 H_2O$ to the aglucone, which he named theveresin, m. p., 140°C.

R. Weitz and A. Boulay[6] also extracted a bitter principle from the kernels which gave with $H_2SO_4$ an orche-yellow coloration, becoming pink after 12 hours.

The above represents the work that has hitherto been recorded in chemical literature on the kernels of the fruit of Thevetia neriifolia. A systematic analysis of the kernels of the seed was therefore undertaken with a view to study the exact chemical nature of the poisonous ingredients contained in it. 68·7 per cent of a non-drying light yellow oil and two crystalline glucosides have been isolated from the kernels of the seeds.

EXPERIMENTAL

Full-grown fruits of Thevetia neriifolia were collected during the months of October and November. After keeping the fruits for about a week the outer green fleshy portion got blackened and were easily removed when the hard nuts were obtained. The nuts contained 22·6 per cent of kernels. The kernels were covered with a light brown coating which constituted 6·4 per cent of it. On estimation, the kernels were found to contain 23 per cent of moisture.

Fifty grammes of the crushed kernels were freed from oil by cold petroleum ether extraction. The oil free powder was put in a flask with 200 c. c. distilled water and few drops of chloroform at room temperature for three days. The

filtrate gave a white flaky precipitate on addition of absolute alcohol. The precipitate was washed with alcohol and added to aqueous-alcoholic solution of hydroquinone kept at 30°C. The solution was slowly coloured green with the formation of quinhydrone, showing thereby the presence of an oxidising enzyme in the precipitate.

Twenty grammes of the oil-free kernels were tested for the presence of alkaloids, but with negative result.

After completely burning the kernels 1·9 per cent of white residue (ash) was obtained, which contained 3·1 per cent of $SiO_2$. The soluble portion of the ash contained phosphate, chloride, nitrate (traces) and magnesium.

The light brown coating of the kernels were carefully separated and 50 g. of it was extracted with ethyl alcohol. The extract was yellowish green in colour. The alcohol was distilled off till about 15 c.c. were left and was kept overnight. Next morning ill-defined soft crystalline mass was found settled at the bottom, which on examination was found to be a mixture of wax and chlorophyll.

For complete analysis 1·5 kilograms of the air dried and crushed kernels were exhaustively extracted with five liters of petroleum ether (b. p. 35—60°C.) in a round bottom extraction flask, till a portion of the extract no longer gave any oily residue on evaporation. The total quantity of the oil obtained amounted to 1,030 g., which corresponded to 68·7 per cent of the kernels. It was a non-drying oil and on purification with Fuller's earth and animal charcoal became very light yellow in colour. It had a sweet bland taste and was entirely free from poisonous properties. In fact its chemical and physical properties corresponded very closely to those of olive oil and in the opinion of the author should form an excellent economic proposition as an article of food and toilet specially in view of the large yield. The oil was not further examined in view of the work already done by Bhattacharya and Ayyar.[3]

The oil-free kernels were completely freed from petroleum ether and successively extracted with rectified spirit till a portion of the extract gave only traces of residue on complete evaporation. The alcoholic extract was concentrated under reduced pressure when a thick brown syrupy liquid, strongly smelling of sugar, was obtained. This slowly solidified to a brown hygroscopic mass in a vacuum desiccator. On extraction with chloroform it gave 40 g. of yellowish brown solid on complete evaporation of the solvent. This substance was completely soluble in ethyl acetate. Traces of oil that was contaminated with it was removed by treatment with petroleum ether. On crystallization from dilute alcohol it was obtained as snow white slender needles melting at 192°C., and having a molecular formula $C_{20}H_{30}O_6$. This was probably the substance which was isolated in the crude form by De Vrij[1] and named by him as thevetin. This substance is insoluble in water but easily soluble in most of the organic solvents It does not reduce Fehling's solution or Tollens reagent, but both of them are readily reduced if the compound is previously hydrolysed by warming with concentrated

hydrochloric acid. It does not produce any coloration or precipitate with the usual alkaloid reagents. Alcoholic ferric chloride, lead acetate or sub-acetate, silver nitrate or calcium chloride have no effect on the substance. When perfectly pure the substance is quite tasteless, but in the presence of only traces of impurities it has a pronounced bitter taste. The substance has been named as ' thevetin ' by the present author after De Vrij who was the first worker in this field.

The residue left after chloroform extraction was freed from the solvent and dissolved in 400 c.c. water with heating. The liquid which was deep brown in colour was allowed to stand with few drops of chloroform to arrest bacterial growth. After about a week white sediment started separating from the mother liquor and within a fortnight the whole of the vessel was full of a white shining deposit. The product was filtered at the pump and on drying weighed 37 g. This on twice crystallization from hot water was obtained as slender shining silky needles, melting at 178°C. This substance which has the molecular formula $C_{16}H_{24}O_8$ differs from thevetin by its solubility in water and intense bitter taste. In its chemical deportments, however, it resembles thevetin very closely, giving no reaction with Fehling's, Tollens and alkaloid reagents, and no precipitate with silver nitrate, lead acetate, ferric chloride or calcium chloride. Basic lead acetate, however, produces an abundant flocculent white precipitate on warming. This substance on hydrolysis reduces Fehling's solution and Tollens reagent readily. In working with this substance great care is necessary as the minutest speck of it inhaled as dust produces intense headache and giddiness. On account of highly poisonous character of the substance it has been named as ' thevetoxin.' The physiological examination of the substance, which is still in progress in the King George's Medical College, Lucknow, indicates it to be a strong cardiac poison.

The mother liquor after the separation of thevetoxin was very dark in colour. The volume was made to 500 c.c. and treated with concentrated solution of tannic acid. A black sticky precipitate separated and the colour of the mother liquor became lighter. Excess of tannic acid in the solution was removed by barium hydroxide solution and excess of barium was precipitated by passing carbon dioxide through the solution. The filtrate, which was light green in colour, contained free reducing sugar and a third substance which yielded the greenish-blue colouring matter on treatment with concentrated hydrochloric acid as observed and described by Warden[4] and which probably may contain the pseudo-indican as supposed by him. But up to this time all attempts in the isolation of the product in a pure crystalline form have ended in failure. At best only little yellow amorphous hygroscopic powder has been obtained which has not yielded any constant analytical data. Its purification has been rendered almost impossible on account of its extreme solubility in all the known solvents, and its non-reactivity towards all known precipitating agents.

*Thevetin,* $C_{20} H_{30} O_8$.—Thevetin dissolves in concentrated sulphuric acid with the production of yellow colour which slowly changes to pink and finally to cherry-red. Thevetin dissolves in strong nitric acid with a yellow colour. It is optically active having a lævo rotation of $\left[ \alpha \right]_D^{30} = - 66\cdot85$ in ethyl alcohol. [Found: C, 65·40, 65·08, 65·29; H, 8·40, 8·34, 8·22; M. W. (cryoscopic in phenol) 373, 350, 371. $C_{20} H_{30} O_8$ requires, C, 65·57; H, 8·19; M. W., 366.]

*Hydrolysis of Thevetin.*—3 g. of thevetin was dissolved in 200 c.c. of ethyl alcohol and 150 c.c. of water containing 2·5 c.c. of hydrochloric acid (d. 1·16) was added. It was refluxed for about an hour. The solution was cooled and carefully neutralized with sodium carbonate solution. It was next concentrated under reduced pressure. A semi-solid sticky substance separated. After sufficient of the substance had separated the upper liquid was removed and the product washed several times with water. The aqueous liquid was evaporated to dryness under reduced pressure and the residue dried over calcium chloride in a vacuum desiccator. It was extracted with acetone and the extract evaporated to dryness. It reduced Fehling's solution and copper acetate in dilute acetic acid solution and was proved to be glucose by its phenylosazone, m. p., 205°C. The aglucone—thevetigenin—on purification with alcohol and animal charcoal was obtained in the form of yellowish white soft mass which settled at the bottom. After some time it became brittle, when it was powdered and put in a vacuum desiccator. It melted at 83°C. Strong sulphuric acid produced a pink-red coloration with a green fluorescence. In concentrated nitric acid thevetigenin dissolved with a yellow coloration which intensified on heating. Alcoholic solution of the substance did not give any precipitate or coloration with ferric chloride.

*Thevetoxin,* $C_{16} H_{24} O_5$:—Thevetoxin dissolves in strong sulphuric acid with orange coloration which intensifies in about five minutes and becomes deep red. On heating the colour darkens with decomposition of the substance. In strong nitric acid it dissolves with yellow coloration. It is insoluble in most of the organic solvents excepting alcohol, in which it is very soluble. It is sparingly soluble in acetone and moderately soluble in water, from which it crystallizes in slender needles. Thevetoxin is optically active, having a lævo rotation of $\left[ \alpha \right]_D^{30} = - 76\cdot1$ in ethyl alcohol. [Found: C, 55·51, 55·60, 54·97; H, 7·33, 7·08, 7·42; M. W. (cryoscopic in phenol) 301, 340, 338. $C_{16} H_{24} O_5$ requires, C, 55.81; H, 7·00; M. W., 344.]

The hydrolysis of thevetoxin was carried out like that of thevetin. The sugar of hydrolysis was proved to be glucose as in the previous case. The aglucone—thevetoxigenin—on treatment with alcohol and animal charcoal gave a light yellow amorphous powder melting at 81°C. It was soluble in chloroform and dissolved in concentrated sulphuric acid forming an yellow coloration which deepened to red, and on heating, blackened with decomposition. It had a mild

but persistent bitter taste.   Alcoholic solution  of the  substance  did  not  give  any
coloration of precipitate  with ferric  chloride.

Further work in this direction is in  progress.

My  best  thanks  are  due  to  Dr.  S.  Dutt  for  the  kind  interest  he  has
taken  in  this  work  and  to  the  ' Kanta  Prasad  Research  Trust '  of  the
Allahabad  University  for  a  scholarship which  enabled  me  to  take  part  in  the
investigation.

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# ON TWO NEW SPECIES OF THE GENUS *CEPHALOGONIMUS* POIRIER FROM WATER-TORTOISES OF ALLAHABAD WITH REMARKS ON THE FAMILY *CEPHALOGONIMIDÆ* NICOLL.

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## INTRODUCTION.

The genus *Cephalogonimus* was created by Poirier in 1886 for *Cephalogonimus lenoiri* parasitic in the intestine of an African turtle, *Tetrathyra vallantii.* The most striking feature of this genus is the position of the genital pore at the extreme anterior end of the body on the dorsal surface in the region of the oral sucker. The genus comprises seven species, of which four are recorded from the reptilia and three from the amphibia. Looss recorded in 1899 the existence of the type species, *C. lenoiri* in *Trionyx nilotica* in Egypt. He also created in the same paper the sub-family *Cephalogoniminæ* to include *Cephalogonimus* and *Emoleptalea* which he defined. Stafford in 1902 described the species *C. americanus* from the intestine of *Rana virescens* and *R. clamata*, the common frogs of North America. Blazoit in 1910 added a third species, *C. europæus* which he obtained from the intestine of the European frog, *Rana esculenta.* Lühe in 1911 found a species in the intestine of the grass snake, *Tropidonotus natrix*, of which he did not give a description. Soon after in 1912 *C. vesicaudus* was found in the intestine of soft-shelled turtles (*Amyda* and *Aspidonetes*) and described by Nickerson. The fifth species, which was named *C. amphiumæ* by Chandler (1923), was obtained from the intestine of a male Urodele, *Amphiuma means* in the United States. Stunkard in 1924 described *C. compactus*, collected from the intestine of *Pseudemys floridana* in the United States. Moghe in 1930 recorded for the first time a species belonging to this genus from India, which he described as *C. emydalis* from the digestive tract of *Emyda granosa*, now called *Lissemys punctata.* The following four species, i.e., *C. ovatus* (Rudolph, 1803), *C. pellucidus* (V. Linstow, 1873), *C. trachysauri* (MacCallum, 1921) and *C. retusus* (Dujardin, 1845 and Odhner 1910), previously assigned to this genus have been removed from it. *C. ovatus* and *C. pellucidus* are now well known as belonging to the genus *Prosthogonimus*. Chandler (1923) excluded *C. trachysauri* from *Cephalogonimus* and also pointed out in the same paper that *C. retusus* and *C. europæus* were identical, a view which was later confirmed by Stunkard (1924).

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As mentioned above the sub-family *Cephalogoniminœ* was created by Looss in 1899 for the genera *Cephalogonimus* and *Emoleptalea*. Nicoll in 1914 founded a new species of *Prothogonimus*, *P. vittellatus*, which he placed under the family *Cephalogonimidœ*. This was the first time when the family name *Cephalogonimidœ* appeared. It was therefore apparent that the sub-family *Cephalogoniminœ* Looss was raised to the rank of a family by Nicoll, who, however, did not give the family diagnosis. Later in 1924 he placed *Cephalogonimus* under the family *Prosthogonimidœ*, which he founded to include the sub-family *Prosthogoniminœ* Lühe, but without diagnosis. Nicoll evidently considered the genus *Prosthogonimus* closely related to *Cephalogonimus* and hence included both these genera in the same family, first in his *Cephalogonimidœ* (1914) and then *Prosthogonimidœ* (1924). In a later paper (1926) he considered both these families as synonymous. Ward in 1917 placed the genus *Cephalogonimus* in the sub-family *Prosthogoniminœ*. Odhner (1911), after discussing the systematic position, came to the conclusion that the genus *Prosthogonimus* belonged to the family Lepodermatidæ. Poche in 1925 followed Odhner in assigning the latter genus to the Lepodermatidae and accepted the family Cephalogonimidae Nicoll for *Cephalogonimus* and *Emoleptalea*, the genera originally included in the sub-family *Cephalogoniminœ* Looss.

The distomes described in this paper belong to new species of the genus *Cephalogonimus* and were obtained from the water-tortoises at Allahabad by Dr. H. R. Mehra, whom my best thanks are due for giving me these worms to study and describe. I am also much indebted to him for valuable help and guidance in this work, which was done under his close supervision.

As will be seen from the discussion given at the end of this paper, I am of opinion that the family *Cephalogonimidœ* should be reduced to the rank of the previously known sub-family *Cephalogoniminœ* Looss within the family Lepodermatidæ. In the general topography of organs the genus *Cephalogonimus* resembles closely the Lepodermatidæ. The only important feature in which it differs is 'the position of the genital pore at the extreme anterior end of the body. But as will be seen from the discussion, the forward position of the genital pore can be explained to be due to a more forward shifting of the latter, and a greater elongation of the cirrus-sac than in some members of Lepodermatidæ, as for instance, the Reniferinæ. In the genus *Emoleptalea* the genital pore lies a little behind anterior end to the right side of the oral sucker.

## Cephalogonimus mehri, n. sp.

A large number, more than one hundred specimens of this species were obtained by Dr. H. R. Mehra from the small intestine of two specimens of soft-shelled tortoises *Lissemys punctata* in September 1930. These tortoises were also found infected with *Astiotrema gangeticus* Harshe. I was, however, unsuccessful in getting this species from the six specimens of *Lissemys punctata* dissected by me during the winter months of 1931.

The distomes are somewhat conical in shape with a broad nearly rounded anterior end and a bluntly pointed posterior end. They are small in size measuring 1˙0—1˙9 mm. in length and 0˙42—0˙57 mm. in greatest breadth, which lies in the region of the intestinal bifurcation.

The cuticle is studded, both on the dorsal and ventral surfaces of the body, with small spines, the finely pointed and hookshaped ends of which are directed backwards. On the dorsal surface the spines extend backwards up to the region of the anterior testis, but on the ventral surface they are present throughout the entire length, except a small posterior terminal part Their absence in the posterior part of the body is probably due to a great proportional growth of the post-acetabular region just before sexual maturity. They are large in number, densely crowded in close set rows in front of the acetabulum especially around the oral sucker, where they are smaller in size and not sharply pointed.

The suckers are nearly spherical in outline. The oral sucker is a little larger than the ventral, measuring 0˙13 to 0˙16 mm in diameter. It lies subterminally with its opening directed towards the ventral surface. The ventral sucker, 0˙1 to 0˙15 mm. in diameter, is situated at 0˙26 to 0˙45 mm. distance, i.e., one-fourth length of the body, behind the anterior end. The measurements of the body, given in the following table, will indicate its exact position.

TABLE I

| Specimen. | Length of body in front of the ventral sucker (in mm.). | Length of body behind the ventral sucker (in mm.). |
|---|---|---|
| 1 | 0˙26 | 0˙75 |
| 2 | 0˙39 | 0˙92 |
| 3 | 0˙37 | 0˙9 |
| 4 | 0˙34 | 1˙1 |
| 5 | 0˙45 | 1˙5 |

The mouth lies at the bottom of the oral sucker and opens into a small, thin-walled prepharynx. The muscular pharynx is oval in outline and is provided with four lobes around its anterior margin. It measures 0˙06—0˙08 mm. in size and divides immediately into the intestinal caeca, the oesophagus being entirely absent. The intestinal caeca lie laterally occupying a position nearer the body wall than the median line and terminate generally a little behind the middle of the body, extending 0˙05—0˙07 mm. distance behind the posterior testis. They are nearly of equal length; only rarely is the right intestinal caecum slightly longer than the left one.

The excretory pore is situated terminally at the posterior end, slightly towards the ventral surface. It opens into a small spherical caudal vesicle, which is interposed between it and the excretory bladder. The caudal vesicle is surrounded by

a group of large parenchymatous cells with prominent nuclei. Its wall is characteristically infolded—the infoldings dividing the cavity, which is continuous in front with that of the median stem of the bladder. The excretory bladder is Y-shaped with the long main stem situated more towards the dorsal side and bifurcating close behind the posterior testis into two small cornua, which extend forwards as far as the middle of the anterior testis. The main stem is wider anteriorly and posteriorly, and is provided with three small diverticula on each side. The cornua are of fairly large diameter and situated internal to the intestinal caeca in the region of the posterior testis, but dorsal to them in the region of the anterior testis.

The genital opening is situated at the anterior end of the body in the mid-dorsal line in front of the oral sucker.

The testes lie obliquely close behind each other, posterior to the ventral sucker, in the second quarter of the body. They are nearly spherical with entire margins; the posterior testis, which lies in the median plane in the middle of the body length, is usually slightly larger, measuring 0·14 – 0·21 mm. in diameter. The anterior testis is situated to the left side, i.e., the side opposite to the ovary and measures 0·14 — 0·17 mm. in diameter. In a few specimens, however, the anterior testis was more broad than long. The vasa efferentia are long thin tubes which arise from the middle of the anterior margin of the testes. The cirrus-sac is large, fusiform and somewhat curved in an S-shaped manner, having thick muscular walls, composed mainly of longitudinal muscle fibres. Its basal end lies in front of the ovary to the right side of the acetabulum and is slightly curved around the latter; sometimes it extends further backwards behind the middle of the ovary. pushing the intestinal caecum of the right side laterally towards the body wall. The cirrus-sac consists of a large sac-like basal portion, which lies obliquely between the acetabulum and the pharynx, and extends forwards to cross ventrally the intestinal caecum of the left side, and a distal long narrow tubular portion, which runs ventrally to the left side of the pharynx and turns dorsally round the oral sucker to open into the genital atrium. The vesicula seminalis is large and filled with sperms. It is situated in the basal part of the cirrus sac and is deeply constricted so as to be divided into two parts—a saccular proximal part occupying the entire space within the basal end of the cirrus sac, and elongated narrower coiled distal part which passes by a narrow duct into the pars prostatica. The pars prostatica of relatively great length has greater breadth proximally, where it is connected with the vesicula seminalis. The deeply staining prostrate gland cells occupy the entire space between the pars prostatica, the convoluted part of the vesicula seminalis and the walls of the cirrus sac.

The ovary, almost spherical in shape, is situated close behind the ventral sucker to the right side. It is smaller than the testes, measuring 0·11—0·15 mm. in diameter. The shell gland complex lies to its left close behind the ventral sucker between it and the anterior testis. The oviduct arises from the inner face of the ovary at its anterior end, and runs medially and slightly posteriorly to enter the shell

gland complex, where it becomes dilated to form the ootype. The ootype is situated more towards the dorsal side and is joined separately by the common vitelline reservoir, the duct of the receptaculum seminis, and pearshaped vesicle of the Laurer's canal. The receptaculum seminis is pearshaped or ovoid situated obliquely to the right side. Its posterior part lies immediately behind the ovary between the latter and the posterior testis. Its narnow anterior part passes towards the shell gland mass to open into the right side of the ootype. The Laurer's canal is broader forming a vesicle at its internal end, where it opens into the ootype at the end opposite to that at which the oviduct joins it. The Laurer's canal takes a backward S-shaped convoluted course, and runs dorsal to the receptaculum seminis to open to the exterior in the mid-dorsal line, in the region of the anterior testis by a minute pore, which is lined by cuticle continuous with that of the body wall. The uterus arises ventrally from the left side of the ootype. It extends backwards to the right side of the anterior testis and ventrally to the receptaculum seminis to reach the hinder end, where it turns forwards as the ascending uterus situated to the left side. The convolutions of the descending and ascending parts are symmetrically arranged and set distinctly apart in a regular manner in the right and left parts of the body, on each side of the main stem of the excretory bladder and ventrally to its cornua. The ascending uterus passes forwards between the shell gland complex and the ventral sucker taking a course parallel and dorsal to the cirrus-sac on its way to the genital atrium The metraterm is absent.

The vitellaria are laterally situated in the body close to the outer side of the intestinal caeca. They are of limited extent consisting of only a few follicles 10—15 in number and extend from the intestinal bifurcation to the hinder end of the ovary. They terminate much in front of the hind ends of the intestinal caeca. The transverse vitelline ducts arise close behind the acetabulum and unite together to form the prominent vitelline reservoir, which enters the anterolateral side of the ootype.

The ripe ova are oval in shape and slightly yellowish in colour, measuring 0'0315 —0'04 mm. in length and 0'018 —0'022 mm. in breadth.

*Cephalogonimus mehri* differs from all the other species of the genus, which have the testes obliquely arranged behind each other, in the form of the body which is conical with the greatest width in the region of the intestinal bifurcation, in the short length of its vitellaria which commence in front of the acetabulum from the intestinal bifurcation and terminate at the posterior end of the ovary much in front of the hinder ends of the intestinal caeca, in the dorsal position of the ootype, in the presence of a pearshaped vesicle at the origin of the Laurer's canal and the host.

## TABLE II

Showing the characteristics of the species of the genus *Cephalogonimus*, having testes obliquely arranged behind each other.

| | C. americanus Stafford, 1902. | C. europaeus Blazoit, 1910. | C. vesicaudus Nickerson, 1912. | C. compactus Stunkard, 1924. | C. mehri n. sp. |
|---|---|---|---|---|---|
| Host | *Rana virescens* and *R. clamata.* | *Rana esculenta.* | *Aspidonectes* and *Amyda.* | *Pseudemys floridana.* | *Lissemys punctata.* |
| Size of suckers | Oral sucker larger than ventral sucker; size 0·26 by 0·24, 0·21 by 0·23. | Oral sucker larger than ventral sucker; diameter 0·30, 0·20. | Oral sucker smaller than ventral sucker; 0·22, 0·27. | Both suckers of the same size; 0·09. | Oral sucker larger than ventral sucker; 0·126—0·158, 0·105—0·147. |
| Oesophagus | Present. | Present. | Absent. | Present. | Absent. |
| Testes | Spherical. Anterior to the left and posterior median in position. | Spherical. Anterior to the left and posterior median. | Elongated transversely. Anterior to the left and posterior median. | Spherical. Anterior slightly to the left and posterior slightly to the right. | Spherical. Anterior to the left and posterior median. |
| Ovary | Almost spherical to the right, close behind ventral sucker. | Spherical to the right of the hinder margin of ventral sucker. | Subspherical close behind the ventral sucker, to the right. | Almost spherical close behind ventral sucker. | Spherical to the right of the posterior margin of ventral sucker. |
| Vitellaria | Extend from half way between the ventral sucker and intestinal bifurcation to near the ends of intestinal caeca. | From intestinal bifurcation to a little in front of blind ends of caeca. | From half way between oral sucker and ventral sucker to the posterior border of posterior testis. | From a little in front of ventral sucker to the ends of intestinal caeca. | From near intestinal bifurcation to hinder margin of ovary. |
| Eggs | 52 μ by 16 μ | 39 μ by 22 μ | 38 to 49 μ by 17 to 21 μ. | 30 to 34 μ by 20 to 23 μ. | 31 to 40 μ by 18 to 22 μ. |

## Cephalogonimus gangeticus, n. sp.

Thirty-five specimens of this species were obtained from the small intestine of one out of fifty specimens of *Trionyx gangeticus* examined by Dr. H. R. Mehra in 1930.

The distomes are small, measuring 4—5˙3 mm. in length and 1˙1—1˙4 mm. in maximum breadth, which lies behind the posterior testis in the region filled with uterine convolutions. The body is elongated and somewhat elliptical, with the posterior end large and broadly rounded and the anterior end somewhat narrower.

The body wall is covered with spines, which hardly project out of the thick cuticle. The spines are thickly set and pointed at their outer ends. They are larger on the ventral surface of the body than on the dorsal surface, where they disappear entirely behind the ventral sucker. On the ventral surface they extend much further behind, but they are altogether absent near the posterior extremity.

The oral sucker is globular and lies subterminally at the anterior end. It is larger than the ventral sucker, measuring 0˙26—0˙32 mm. in diameter. The ventral sucker measures 0˙24—0˙28 mm. in diameter and is situated at about one-third distance from the anterior end of the body, as will be seen from Table I.

The mouth faces towards the ventral surface and opens into a thin-walled prepharynx. The latter leads into a muscular pharynx of oval outline and 0˙08—0˙11 mm. length and 0˙12—0˙14 mm. breadth. The pharynx appears to be produced into four lobes at its anterior margin. A short œsophagus of 0˙05—0˙11 mm. length is present. The intestinal bifurcation lies far in front of the ventral sucker. The intestinal caeca terminate in front of the posterior end of the body at about the middle of the distance between it and the posterior testis.

The excretory pore is subterminal and ventral. It opens into a spherical caudal vesicle which lies between it and the excretory bladder. The walls of the caudal vesicle are produced inwards into folds, which divide its cavity into a corresponding number of pockets. The main stem of the excretory bladder lies in the median plane, pressed closely to the dorsal body wall. It divides immediately behind the posterior testis into the right and left cornua, which give it a Y-shaped appearance. The main stem receives behind the posterior testis, three lateral branches on each side which are subdivided into a number of finer tubes near the lateral margins of the body. The cornua of the bladder extend forwards outside the testes and the intestinal caeca, terminating at the middle of the ovary, where each divides into two branches. The latter extend forwards as far as the middle of vesicle seminalis and are branched throughout their course. The excretory system differs from that of *Cephalogonimus lenoiri* Poirier only in the presence of the caudal vesicle.

The genital pore lies at the end of a papilla situated at the extreme anterior end on the dorsal side in front of the oral sucker. The testes are situated one behind the other in the median plane of the body and are transversely elongated with entire or irregular margins. The anterior testis lies 0˙64—0˙73 mm. distance behind the ventral sucker and measures 0˙23—0˙38×0˙4—0˙58 mm. in size. The

posterior testis is situated 0'16—0'42 mm. distance behind the anterior testis, measuring 0'16—0'34 × 0'32—0'74 mm. The vasa efferentia arise from the middle of the anterior face of the testes and run forwards independently as narrow tubes right up to the base of the cirrus sac, where they unite to form a small inconspicuous vas deferens. The cirrus sac is large and fusiform, lying obliquely between the intestinal caeca, with the posterior end terminating immediately in front of the ventral sucker or extending up to the centrum of the latter. It has highly muscular walls composed mainly of longitudinal muscle fibres. It is narrow and tubular in its terminal part, which lies ventral to the left intestinal caecum before it opens into the genital atrium. The vesicula seminalis occupies basal part of the cirrus sac and consists of two parts; a broad proximal part, which is covered by a thin layer of longitudinal fibres and a strongly coiled distal part having thick muscular walls. The pars prostatica and ejaculatory duct are long. The pars prostatica is lined by an epithelium of columnar cells surrounded outside by a layer of circular muscle fibres. The prostate gland cells form a huge mass filling entirely the intervening space between the distal part of the vesicula seminalis, pars prostatica and the walls of the cirrus sac. The protusible cirrus is small and unarmed.

The ovary is subspherical, measuring 0'28—0'36 × 0'24—0'32 mm. It lies to the right side immediately behind the ventral sucker with the outer margin touching right intestinal caecum. From its inner side about the middle of its length arises the oviduct, which after running towards the median line turns backwards to dilate into the ootype. The ootype is surrounded by a prominent shell gland mass of a smaller size than the ovary, which is situated about half way between the anterior testis and the acetabulum, somewhat nearer the former than the latter. The receptaculum seminis, ovoid in shape, measures 0'32—0'37 × 0'18—0'22 mm. in size It is obliquely situated to the right between the ovary and the anterior testis and opens dorsally by a short duct into the ootype. The Laurer's canal is long and convoluted, lying ventral to the receptaculum seminis. It opens to the exterior on the dorsal surface of the body by a minute pore close in front of the anterior testis. Internally it joins the ootype near the posterior margin. The common vitelline reservoir opens ventrally into the ootype. The first convolution of the uterus arises from the left side of the ootype and passes a little forwards before it turns backwards to form a loop, which winds to the left side as the descending uterus in numerous irregular and closely packed convolutions up to the hinder end of the body. The ascending uterus is also highly convoluted and situated to the right side of the body parallel to the descending uterine convolutions. Sometimes the arrangement of the descending and ascending parts of the uterus is reversed, i.e., the descending part is situated to the right and ascending to the left. As the entire post-testicular region is filled with uterine coils and lateral branches of the excretory bladder, the parenchyma is scarcely seen in this region. In front of the shell gland complex the ascending uterus passes dorsal to the ventral sucker and

the cirrus sac, terminating in the metraterm. The metraterm is well developed in this species, extending between the hinder end of the pharynx and the anterior end of the oral sucker. It opens to the right side of the male pore in the small genital atrium situated at the end of the genital papilla.

The vitelline glands are strongly developed commencing near the posterior end of the ventral sucker, and terminating at the posterior end or a little behind the posterior testis. They lie laterally, mainly in the extracaecal zone, but they also overlap the intestinal caeca extending inwards towards the median line. The two vitelline ducts, one from each gland, pass transversely anterior to the cephalic testis, where they unite in the median line to form the common vitelline reservoir, which discharges into the ootype.

The ripe eggs are oval in shape and yellowish in colour, measuring 0·024—0·028 mm. in length and 0·015—0·019 mm. in breadth.

*C. gangeticus* resembles the type species, *C. lenori* Poirier, in the subterminal position of the oral sucker, excretory system, fusiform shape of the cirrus-sac, position of the ovary to the right side of the ventral sucker and the uterus having a characteristic loop at its commencement. But it differs in the larger size of its body, in having the oral sucker larger than the ventral sucker, presence of a caudal vesical at the end of the excretory bladder, position of the ventral sucker at one-third distance from the anterior end, shape and size of the testes, larger size of the receptaculum seminis, absence of a pear-shaped vesicle at the origin of the Laurer's canal, asymmetrical arrangement of the uterine convolutions and greater length of the vitellaria.

*C. gangeticus* also resembles *C. amphiumae* Chandler, in having body of nearly same size and the maximum width in the post-testicular region, subterminal position of the oral sucker and its larger size than that of the ventral sucker, possessing a caudal reservoir at the end of the excretory bladder, asymmetrical arrangement of the uterine coils and great length of vitellaria. But it differs remarkably in the size of the suckers, ventral sucker being more posterior than in *C. amphiumae*, œsophagus intermediate in length between that of *C. amphiumae* and *C. lenoiri*, in the shape and position of the testes and the cirrus sac, size and shape of the receptaculum seminis, which opens into the ootype dorsally instead of ventrally as in *C. amphiumae* and the host.

The new species also resembles, in a few features, *C. emydalis* Moghe, such as the presence of a caudal vesicle, oral sucker being larger than the ventral sucker, testes transversely elongated, the vitellaria extending from the level of the ventral sucker to a point behind the posterior testis. But the important points, in which *C. gangeticus* differs from *C. emydalis*, are larger size of the body, subterminal position of the oral sucker, acetabulum situated more towards the posterior end, presence of an œsophagus, cirrus sac not coiled on itself near the intestinal bifurcation as in *C. emydalis*, larger size of the testes and ovary, position of the ovary to the right side and not immediately behind the ventral sucker, larger size

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and oval form of the receptaculum seminis, uterine coils passing ventrally and not laterally to the testes and the vitellaria overlapping the intestinal caeca instead of being restricted to the lateral fields of the body.

The above-mentioned differences are prominent enough to justify the creation of a new species, for which I give the following diagnosis.

Spines on the dorsal side restricted to the preacetabular region ; oral sucker larger than the ventral sucker and situated at one-third distance from anterior end; short oesophagus present; caudal vesicle of the excretory bladder having infolded walls; testes transversely elongated and of large size situated in second-third of the body; cirrus sac fusiform, terminating near the centrum of the ventral sucker; ovary subspherical, situated to the right side of the ventral sucker ; shell gland complex to the left side of the ovary ; uterine convolutions passing ventral to the testes; metraterm present; genital pore at the end of a protrusible papilla on the dorsal side in front of the oral sucker; eggs oval and yellowish, measuring 0·024—0·028 mm. in length and 0·015—0·019 mm. in width. Host. *Trionyx gangeticus.* Locality Allahabad.

## TABLE III

### Dimensions in mm. of specimens of *C. gangeticus*, n. sp.

| Specimen. | Size of body. | Length in front of the ventral sucker. | Length behind the ventral sucker. | Diameter of oral sucker. | Diameter of ventral sucker. | Size of pharynx. | Size of anterior testis. | Size of posterior testis. | Size of ovary. | Size of receptaculum seminis. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 5·32 × 1·21 | 1·72 | 3·6 | 0·3 | 0·28 | ... | 0·38 × 0·51 | 0·32 × 0·74 | 0·36 × 0·32 | 0·37 × 0·19 |
| 2 | 5·08 × 1·11 | 1·71 | 3·37 | 0·28 | 0·26 | 0·11 × 0·13 | 0·27 × 0·58 | 0·26 × 0·63 | 0·36 × 0·3 | 0·32 × 0·19 |
| 3 | 4·27 × 1·15 | 1·34 | 2·93 | 0·26 | 0·24 | ... | 0·3 × 0·4 | 0·34 × 0·58 | 0·28 × 0·24 | ... |
| 4 | 5·06 × 1·37 | 1·72 | 3·34 | 0·32 | 0·27 | 0·11 × 0·14 | 0·37 × 0·37 | 0·32 × 0·32 | 0·36 × 0·31 | 0·32 × 0·22 |
| 5 | 4·85 × 1·15 | 1·61 | 3·24 | 0·3 | 0·27 | 0·11 × 0·44 | 0·3 × 0·53 | 0·21 × 0·7 | ... | 0·37 × 0·21 |
| 6 | 4·0 × 1·5 | 1·28 | 2·72 | 0·26 | 0·24 | 0·08 × 0·12 | 0·23 × 0·51 | 0·16 × 0·69 | 0·28 × 0·32 | 0·33 × 0·18 |

TABLE IV

Showing diagnostic characters of the species of the genus *Cephalogonimus* having testes in tandem.

| | C. lenoiri Poirier, 1886. | C. amphaumae Chandler, 1923. | C. emydalis Moghe, 1930. | C. gangeticus n. sp. |
|---|---|---|---|---|
| Host | Tetrabdegra vallantii. | Amphaauma means. | Emyda granosa. | Trionyx gangeticus. |
| Body length | 3·0 | 4·4—5·3. | 1·87—2·45. | 4·0—5·32. |
| Maximum width | 1·0 at level of female genital organs. | 1·22—1·30 in third-fifth of body behind posterior testis | 0·6—0·73 at level of anterior testis. | 1·11—1·37. |
| Size of suckers | Oral sucker subterminal, smaller than ventral sucker, which is situated a little in front of middle of body; diameter 0·24; 0·29. | Oral sucker subterminal larger than ventral, which is placed at two-sevenths of body length from anterior end; diameter 0·42—0·43, 0·368—0·38. | Oral sucker terminal, larger than ventral, which lies in anterior fourth of body; diameter, 0·168, 0·137. | Oral sucker larger than ventral sucker, which lies at one-third body length from the anterior end; diameter 0·26—0·32, 0·24—0·28. |
| Pharynx | Breadth 0·16, and length 0·11. | Diameter 0·192. | Diameter 0·092. | Breadth 0·12—0·14 and length 0·08—0·11. |
| Oesophagus | Present, length 0·15. | Barely distinct. | Absent. | Short, length 0·05—0·11. |
| Testes | Ovoid and simple, in the first part of second-half body. | Nearly rounded, in contact. Diameter of anterior 0·41—0·48 and posterior 0·30—0·47. | Transversely elongated. Anterior measures 0·146—0·198 by 0·2—0·225, and posterior 0·123—0·156 by 0·19—0·23. | Transversely elongated. Anterior 0·23—0·38 by 0·4—0·58; posterior 0·16—0·34 by 0·32—0·74. |
| Cirrus sac | Fusiform, lying obliquely between intestinal caeca. | Long and flask-shaped, lying obliquely between intestinal bifurcation and ventral sucker. | Large, lying obliquely between intestinal caeca, coils once on itself near intestinal bifurcation. | Fusiform, lying obliquely between intestinal caeca. |
| Ovary | Spherical, just behind ventral sucker, to its right, nearly in the middle of body. | Spherical, immediately posterior to ventral sucker, slightly to its right with its centre about one-third of the body length from anterior end. | Nearly round, lies just behind ventral sucker and slightly anterior to middle of the body. | Subspherical, immediately posterior to ventral sucker, to its right. |

TABLE IV —(contd.)

| | C. lenovi Poirier, 1886. | C. amphiumae Chandler, 1923. | C. emydalis Moghe, 1930. | C. gangeticus n. sp. |
|---|---|---|---|---|
| Receptaculum seminis ... | Flaskshaped. | Flaskshaped. | Round. | Ovoid. |
| Uterus. ... | With symmetrical coils. | Irregularly coiled. | Convolutions symmetrically arranged. | Irregularly coiled. |
| Vitellaria ... | Follicles in anterior half of body behind ventral sucker. | Extend from a level just behind anterior end of the ventral sucker to level of posterior testis and on the left side the follicles are more extensive. | Follicles commence at the level of the ventral sucker extending to a point mid way between testes and ends of intestinal caeca, extent on left slightly long. | Begin near the posterior end of ventral sucker and extend up to posterior end of caudal testis or little behind it. |
| Eggs ... | 35 by 17 $\mu$. | 26 by 13 $\mu$. | 27 by 11 $\mu$. | 24—28 $\mu$ by 15—19 $\mu$. |

# KEY TO THE SPECIES OF THE GENUS *CEPHALOGONIMUS* POIRIER

The genus is divided into two groups on the basis of the testes, whether they lie in tandem or obliquely behind each other.

## GROUP I.

Testes in tandem, one behind the other.
A.  Oral sucker smaller than the ventral sucker . . . . . . *C. lenoiri* Poirier, 1886.
    Oral sucker larger than the ventral sucker . . . . B.
B   Oesophagus absent . . . *C. emydalis*, Moghe, 1930.  Oesophagus present. C.
C.  Testes nearly rounded, *C. amphiumae*, Chandler, 1923
    Testes transversely elongated *C. Gangeticus*, n. sp.

## GROUP II.

Testes placed obliquely behind each other  Genital opening at some distance behind anterior end on the dorsal side of oral sucker-A
A.  Genital pore median ... *C, americanus* Stafford, 1902.
    Genital pore lateral to the right side. . . . . . . . . .*C. europaeus*, Blazoit, 1910.
    Genital pore situated at the anterior tip of the body. . . . . . B.
B.  Oral sucker smaller than ventral sucker. . . . . . *C. vesicaudus* Nickerson, 1912.
    Both suckers of the same size. *C. compactus* Stunkard, 1924.
    Oral sucker larger than ventral sucker . . . *C. mehri*, n. sp.

## Discussion on the Systematic position of the family Cephalogonimidae.

The family Cephalogonimidae resembles the family Lepodermatidae in the following characters:—
(1)  Cuticle spinose.
(2)  Prepharynx, pharynx and oesophagus present.
(3)  Excretory bladder typically Y-shaped, with long median stem and two short lateral diverticula.
(4)  Ovary in front of the testes, behind the acetabulum and usually to the right side.
(5)  Testes usually near middle of the body, obliquely or directly behind each other.
(6)  A muscular cirrus sac containing seminal vesicle, pars prostatica, prostate gland cells and a cirrus.
(7)  Uterus highly convoluted, filling the posterior half of the body, generally arranged as descending and ascending parts to the right and left sides.
(8)  Yolk glands of varying length restricted to the sides of the body.

The topography of organs in the genera *Cephalogonimus* and *Emioleptalea* are so similar to that in the family Lepodermatidae that it is hardly possible to separate them from that family. The only characters, which appear to distinguish them from the Lepodermatidae are:—
(1)  Position of the genital pore at the extreme anterior end of the body.

(2) Bifurcation of the main stem of the excretory bladder immediately behind the posterior testis and not in front of the testes as in the Lepodermatidae.

(3) Branched condition of the main stem as well as the cornua of the excretory bladder.

and (4) Uterine coils passing ventrally or laterally to the testes and not between them as in the latter family.

But these characters are not of such systematic importance as to justify the creation of the family Cephalogonimidae. On the other hand, it appears that all of them except the first one are also met with in certain genera of the Lepodermatidae.

In the genera *Renifer* Pratt, *Ochetosoma* Braun, *Lechriorchis* Stafford of the sub-family *Reniferinae* Pratt, the genital pore occupies an extreme lateral and forward position, *i.e.*, near the pharynx and the cirrus sac is long extending to the centrum of the ventral sucker. In the genera *Mediorima, Dasymetra, Platymetra* and *Xenopharynx*, which Mehra includes in the *Reniferinae*, the genital pore is median close behind or on the intestinal bifurcation. Mehra considers these genera to be the primitive Reniferinae combining in themselves with the typical characters of the *Reniferinae*, certain primitive features which are met with in the genus *Styphlodora*. He takes a form like *Styphlodora* to represent the basis of evolution from which the *Reniferinae* have arisen through such intermediate forms as *Mediorima* and *Dasymetra*. Proceeding on the same evolutionary hypothesis we can derive the terminal position of the genital pore of the Cephalogonimidae if we imagine that the genital pore of such forms as *Renifer* and *Ochetosoma* has become shifted further forwards so as to lie at the extreme anterior end and the cirrus sac has become much more elongated and narrowed in its terminal part than in the typical Lepodermatidæ. It is well known that the position of the genital pore varies considerably in the family Lepodermatidæ and it should not be surprising if in certain genera such as *Cephalogonimus* it has come to occupy an extremely anterior position, *i.e.*, in front of the oral sucker. In the genus *Emoleptalea* the genital pore lies to the right side of the oral sucker. Even in the genus *Cephalogonimus* the position of the genital pore varies. In the two species, *C. americanus* and *C. retusus*, it lies either median or to the side, on the dorsal side of the oral sucker, a little distance behind the anterior end; whereas in all the other species of the genus it lies further forwards at the extreme anterior tip of the body. It is evident that former condition is primitive indicating a further forward shifting of the pore than in the typical Reniferinæ.

It may be pointed out that in the genera *Prosthogonimus* and *Schistogonimus* the genital pore lies near the extreme anterior end to the left side of the oral sucker and the cirrus-sac does not extend as far as the ventral sucker but it terminates a little behind the intestinal bifurcation. In *Prosthogonimus anatinus* the male genital duct opens on a papilla near the anterior end of the oral sucker. The condition in *Prosthogonimus* confirms the view that with the gradual shifting

forward of the genital pore the relation of the basal part of the cirrus sac with the acetabulum has become correspondingly changed.

The presence of lateral branches in the excretory bladder is a character not peculiar to Cephalogonimidæ. We also find the main stem and the cornua provided with lateral branches in several genera of the family Lepodermatidæ. It was this character which led Baer to divide the Lepodermatidæ Odhner into two families, Lepodermatidæ and Reniferidæ. Subsequent workers, among whom Poche and Mehra may be mentioned, have criticised this classification. It is therefore obvious that this character is not of such importance as to force us to retain the family Cephalogonimidæ.

The bifurcation of the main stem of the excretory bladder behind the posterior testis should not be considered as an important difference between the two families. The main stem of the excretory bladder is considerably longer than the cornua in all the species of the genus *Cephalogonimus* as is the case in the Lepodermatidæ. The bifurcation of the main stem of the bladder behind the the testes in *Cephalogonimus* can be easily explained to be due to the crowding together of the testes, the ovary and the receptaculum seminis in the median plane of the body so as to leave practically no space for the main stem of the excretory bladder to extend forwards in that region. Hence the bifurcation of the main stem into cornua has taken place behind the testes, there being ample space on the lateral sides in that region for the cornua to proceed forwards in their course.

As the testes have come to lie very close together in the median plane leaving no space between them for the uterine coils to pass through in *Cephalogonimus*, the arrangement of uterine convolutions has consequently taken a slightly different course than in many Lepodermatidæ in that descending and ascending parts of the uterus do not pass between the testes but ventrally or laterally to them, to fill the post-testicular region of the body.

In view of what has been said above it appears beyond doubt that the family Cephalogonimidæ is untenable. This family should be reduced to the rank of a sub-family within the family Lepodermatidæ Odhner. The sub-family Cephalogoniminæ resembles the sub-family Reniferinæ in the presence of spines on the integument; termination of the intestinal caeca at some distance in front of the posterior end of the body; the excretory bladder provided with lateral branches; tendency of the genital pore to shift more forwards towards the anterior end; cirrus sac having in its basal part a coiled vesicula seminalis, followed by a long tubular pars prostatica; position of the ovary and testis behind the ventral sucker and the configuration of the uterus.

Diagnosis of the sub-family Cephalogininiminæ Looss, 1899 (Cephalogonimidæ Nicoll, 1914.) :—

Lepodermatidæ; small size: beset with spines in a part of or entire length of the body; œsophagus short or absent; excretory vesicle Y-shaped consisting

of a long median stem and short cornua, and provided with lateral branches; genital pore situated at extreme anterior end on the dorsal side or a little behind it in the region of the oral sucker; testes in tandem or obliquely situated one behind the other; cirrus sac long having a curved shape, containing a coiled vesicula seminalis and a long pars prostatica: ovary, spherical or sub-spherical, pretesticular, situated to the right side of the posterior end of acetabulum; receptaculum seminis and Laurer's canal present; uterus much con-voluted filling post-testicular region with convolutions in ascending and descending parts to the right and left sides and passing ventral or lateral to the testes.

Parasites of amphibia, reptilia and birds.

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Fig. 1

Fig. 2

Fig. 3

Fig. 4

p.

pars.p.

L.C.

U.Sem

C.S.

S.d.

o.

r.s.

a.t.

Vit.

p.t.

u.t.

1.m.m.

Fig. 5

g.p a p

1 m m

e.o.
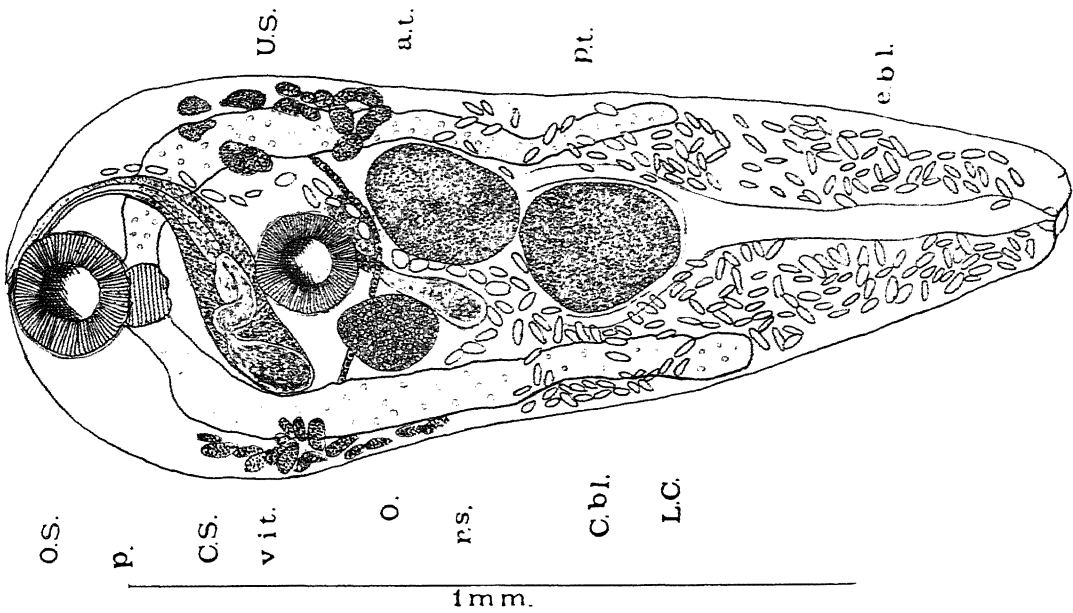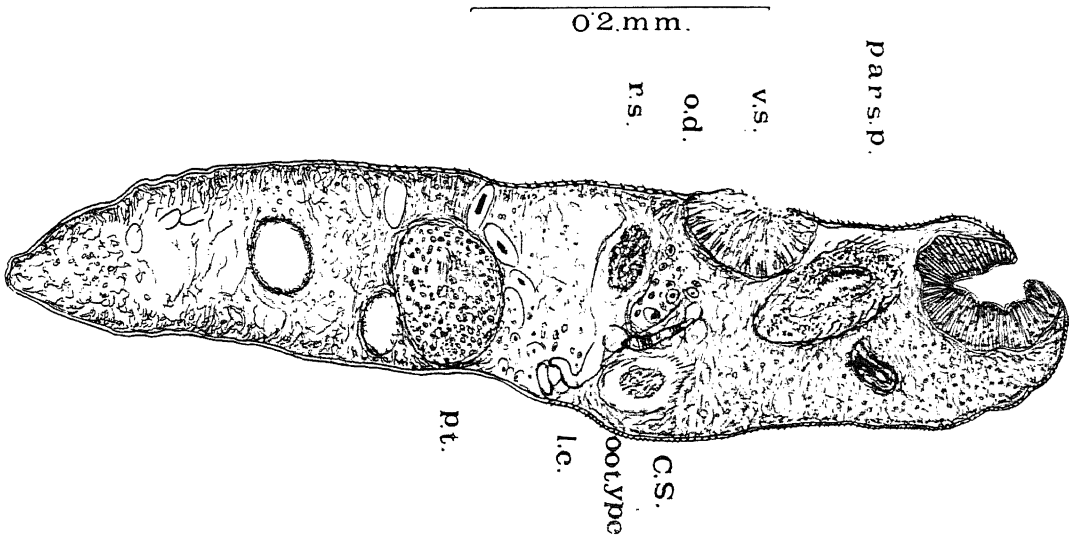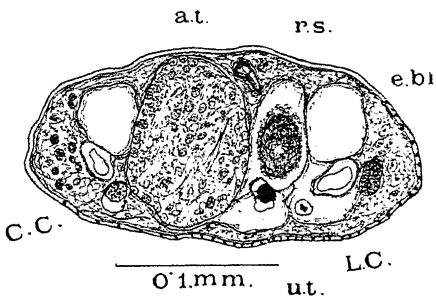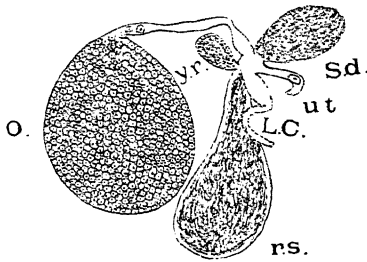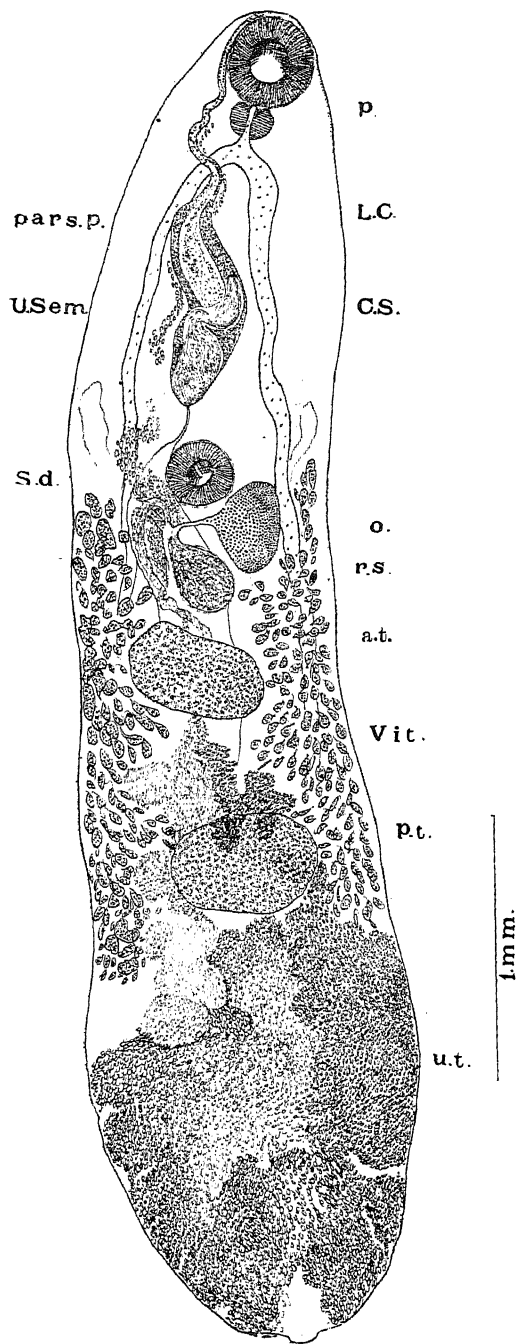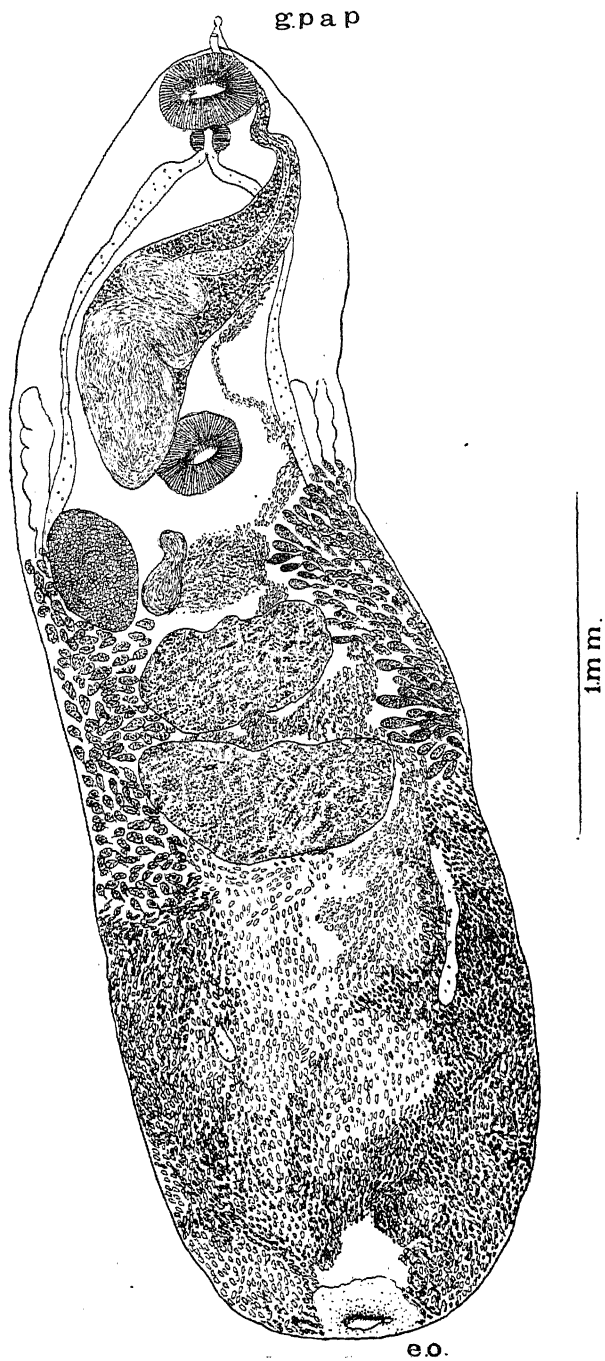
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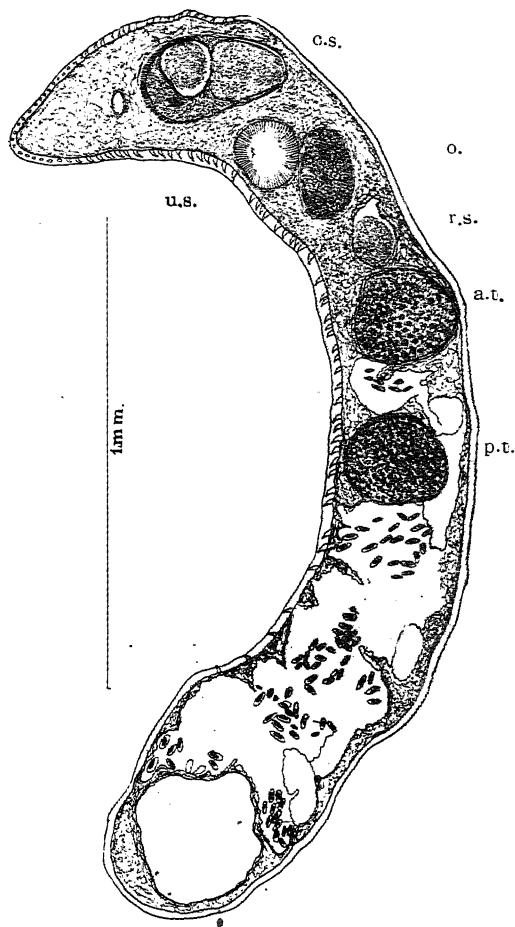
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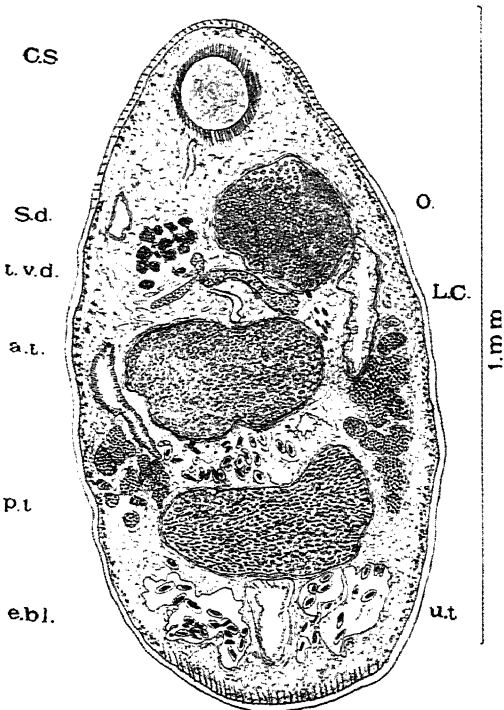
Fig. 8
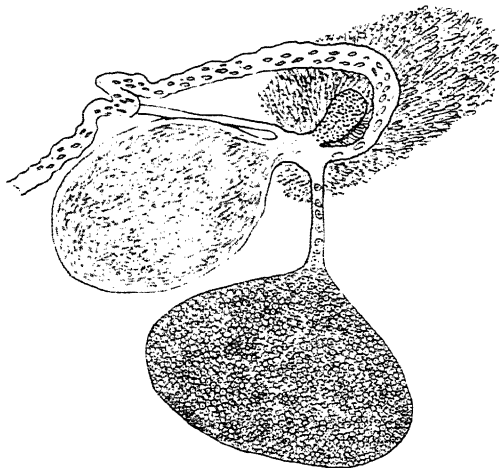
Fig. 9

# EXPLANATION OF PLATES AND KEY TO LETTERING
## USED IN FIGURES

Figures 1—4. *Cephalogonimus mehri.*

1. Ventral view of a specimen.
2. Vertical-longitudinal section through posterior testis, Laurer's canal, receptaculum seminis and oviduct.
3. Transverse section through anterior testis, receptaculum seminis and Laurer's canal.
4. Diagrammatic view of female sexual organs constructed from a series of longitudinal sections.

Figures 5—9. *Cephalogonimus gangeticus.*

5. Dorsal view of a specimen.
6. Ventral view of a specimen.
7. Vertical-longitudinal section through testes, receptaculum seminis and ovary.
8. Horizontal-longitudinal section through testes, ovary, yolk reservoir and Laurer's canal.
9. Diagrammatic view of female sexual organs.

a. t., anterior testis; b. w., body wall; c. bl., cornua of bladder; c. s., cirrus sac; e. bl., ex-cretory bladder; e. o., excretory opening; g. p., genital pore; g. pap., genital papilla; i. c., intestinal caecum; L. C., Laurer's canal; o., ovary; o. d., oviduct; oes., œsophagus; o. s, oral sucker; p., pharynx; p. p., prepharynx; pars. p., pars prostatica; pros., prostate gland; p. t., posterior testis; r. s., receptaculum seminis; s. g., shell gland; t. v. d., trans-vitelline duct; ut., uterus; v. e., vasa efferentia; v. s., ventral sucker; v. sem., vesicula seminalis; vit., vitellaria; y. r., yolk reservoir.

# SPECTRA OF TREBLY AND QUADRUPLY IONISED LEAD

By Jai Kishen

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## Spectrum of Pb$_{IV}$

The spectrum of trebly ionised lead was first investigated by Carroll,[1] but there were several points in his analysis which remained obscure. The recent accurate measurements of Arvidsson[2] for the spark spectra of lead in the Schumann region have been utilised in this paper to improve upon the existing analysis.

Carroll expressed doubt as to which of the two pairs

$$\lambda \ 1029, 1313$$

$$\text{and } \lambda \ 1049, 1313$$

may be identified as belonging to $6s\,^2S-6p\,^2P$ transition. Arvidsson has shown that $\lambda$ 1049 belongs to Pb$_{III}$ and this therefore establishes the identity of $\lambda\lambda$ 1029, 1313 as the fundamental pair, and is in conformity with the analysis of Rao and Narayan.[3]

Regarding the allocation of $6p\,^2P-6p\,^2D$ lines, we have adopted the scheme of S. Smith,[4] as being most plausible, and this is also borne out by the experimental observations of Arvidsson. S. Smith has further identified the lines of higher transitions, viz.—

$$6d\,^2D-7p\,^2P$$

$$7s\,^2S-7p\,^2P$$

$$7p\,^2P-7d\,^2D$$

The first two multiplets are quite correct, but the identification of $\lambda\lambda$ 2508·98, 3087·10 and 3145·60 as $7p\,^2P-7p\,^2D$ is not justified in the light of the data supplied by Arvidsson, and the lines 2508·98 and 3145·60 are here classified as belonging to $7p\,^2P-8s\,^2S$ group. This is supported by the presence of the lines:

| | |
|---|---|
| 576·43 (2) | $6p\,^2P_1-8s\,^2S$ |
| 656·09 (2) | $6p\,^2P_2-8s\,^2S$ |

The lines $\lambda\lambda$ 917·89 and 1137·86 originate from $6p\,^2P-7s\,^2S$ combination.

The revised list of Pb$_{IV}$ lines so far classified is given in Table 1.

## TABLE I

| $\lambda$ | I | $\nu$ | Combinations |
|---|---|---|---|
| 1028·61 | 30 | 97218·6 | $6s\ ^2S_1 - 6p\ ^2P_2$ |
| 1313·06 | 40 | 76158·0 | $6s\ ^2S_1 - 6p\ ^2P_1$ |
| 917·89 | 7 | 10894·6 | $6p\ ^2P_1 - 7s\ ^2S_1$ |
| 1137·86 | 7 | 87884 | $6p\ ^2P_2 - 7s\ ^2S_1$ |
| 922·49 | 10 | 108402 | $6p\ ^2P_1 - 6d\ ^2D_2$ |
| 1116·08 | 7 | 89599 | $6p\ ^2P_2 - 6d\ ^2D_3$ |
| 1144·95 | 6 | 87340 | $6p\ ^2P_2 - 6d\ ^2D_2$ |
| 576·43 | 2 | 173482 | $6p\ ^2P_1 - 8s\ ^2S_1$ |
| 656·09 | 2 | 152418 | $6p\ ^2P_2 - 8s\ ^2S_1$ |
| 459·04 | 6 | 217846 | $6s\ ^2S_1 - 7p\ ^2P_2$ |
| 3002·78 | 2 | 33292·8 | $6d\ ^2D_2 - 7p\ ^2P_2$ |
| 3221·3C | 8 | 31034·4 | $6d\ ^2D_3 - 7p\ ^2P_2$ |
| 3962·45 | 6 | 25229·8 | $6d\ ^2D_2 - 7p\ ^2P_1$ |
| 4049·79 | 4 | 24685·7 | $7s\ ^2S_1 - 7p\ ^2P_1$ |
| 3052·66 | 7 | 32748·8 | $7s\ ^2S_1 - 7p\ ^2P_2$ |
| 2508·98 | 2 | 39844·8 | $7p\ ^2P_1 - 8s\ ^2S_1$ |
| 3145·60 | 2 | 31781·3 | $7p\ ^2P_2 - 8s\ ^2S_1$ |

Applying Hick's formula to the series $6p^2P - ns^2S$ ($n=6, 7, 8$) the value of the fundamental $^2S$ comes out as 340186, giving an ionisation potential of 4·19 Volts. The terms of $Pb_{iv}$ calculated on this basis are given in Table II.

## TABLE II

|  | 6 | 7 | 8 |
|---|---|---|---|
| $ns_1\,^2S$ | 340186 | 155084 | 90544 |
| $np^2P$ | 264028 | 130398 |  |
| $ny^2P_2$ | 242968 | 122335 |  |
| $nd^2D_2$ | 155627 |  |  |
| $^2D_3$ | 153369 |  |  |

Arvidsson's list of Pb$_{III}$ lines gives a number of strong lines between $\lambda$ 450 to $\lambda$ 600. These probably belong to the transition $5d^{10}$ $6s^2 S - 5d^9$ $6s$ $6p^4, ^2$(FDP). But the terms originating from the combination $5d^9$ $6s$ $6p$ can be identified only by their combinations with the terms of the configurations $5d^9$ $6s$ $6d$ or $5d^9$ $6s^2$ $^2D$. The data for the first transition is not available, and for the second. only partially. Attention, however, is directed to the presence of the following pairs with separation of about 21316.

| | | | | |
|---|---|---|---|---|
| 92524 (3) | 95772 (3) | 98768 (3) | 112269 (8) | 118209 (3) |
| 71207 (1) | 74455 (4) | 77454 (2) | 90953 (1) | 97893 (3) |

It is possible that 21316 represents the $^2D$ – separation of $5d^9 6s^2$ combination, for it agrees well with the corresponding separations in Au$_I$ (12274), Hg$_{II}$ (15040) and Tl$_{III}$ (18616).

## SPECTRUM OF PB V

Mack[5] has analysed about a dozen lines of Pb$_V$. He has obtained $^3D_{3,2}$ and $^1D_2$ terms of $5d^9$ $6s$, and $^3P_2$, $^1P_1$, $^3F_{4,3,2}$ and $^3D_3$ of $5d^9$ $6p$ combination. With the help of Arvidsson's data it has been possible to extend the analysis and obtain many more terms. The separation $^3D_3 - {}^3D_1$, of $5d^9$ $6s$ should be a little less than 22000 as derived from the sequence given in the following table: —

| Element. | $^3D_3 - {}^3D_1$ |
|---|---|
| Pt$_I$ | 10132 |
| Au$_{II}$ | 12728 |
| Hg$_{III}$ | 15556 |
| Tl$_{IV}$ | 18613 |

Since the separation of $^3D_3 - {}^3D_2$ in Pb$_V$ is 3936, $^3D_2 - {}^3D_1$, should be a little less than 18050. Several pairs with frequency interval 18007 have been obtained which fit in with the lines already analysed by Mack. The multiplets obtained are given in the table below.

## TABLE III

| $5d^9\,6p$ ＼ $5d^9\,6s$ | $^3D_3$ | *3940* | $^3D_2$ | *18007* | $^3D_1$ | *3286* | $^1D_2$ |
|---|---|---|---|---|---|---|---|
| $^3P_2$ *24687* <br> $^3P_1$ *19930* <br> $^3P_0$ | 84036·6 <br> M* 1189·93 (9) | | 80098·0 <br> M 1248·47 (6) <br> 104785· <br> 954·34 (7) | | 86775·0 <br> 1152·40 (1) <br> 106705· <br> 937·16 (3) | | 83492·7 <br> 1197·71 (6) |
| $^1P_1$ | | | 113130· <br> M 883·94 (7) | | 95123·9 <br> 1051·26 (2) | | 91838·3 <br> M 1088·87 (5) |
| $^3D_3$ *—9440* <br> $^3D_2$ *30524* <br> $^3D_1$ | 115742· <br> M 863·99 (15) <br> 106302· <br> 940·72 (1) | | 111807· <br> M 894·40 (8) <br> 102362· <br> 976·93 (5) <br> 132899· <br> 752·51 (1) | | 84357· <br> 1185·43 (8) <br> 114882· <br> 870·45 (7) | | 90514·1 <br> M 1104·81 (3) <br> 81070·8 <br> 1233·48 (10) <br> 111598· <br> 896·07 (7) |
| $^1D_2$ | | | 129955· <br> 769·50 (5) | | | | 108664· <br> 920·27 (7) |
| $^3F_4$ *—7839* <br> $^3F_3$ *10779* <br> $^3F_2$ | 110301· <br> M 906·61 (10) <br> 102362· <br> 976·93 (5) <br> 113141· <br> M 883·85 (7) | | 98428· <br> 1015·97 (1) <br> 109204· <br> M 915·72 (9) | | 91197· <br> 1096·52 (4) | | 77134· <br> 1296·43 (3) <br> M 87911·3 <br> 1137·51 (5) |

ᵏ Lines followed by M are originally classified by Mack.[5]

The separations and the relative positions of the terms of the above combinations are as expected from the corresponding terms of the preceding elements.

### References

[1] J. A. Carroll, *Phil. Trans.* 225, 357, 1926.

[2] G. Arvidsson, *Ann d Physik*, 12, 787, 1932.

[3] Rao & Narayan, *Zs. f., Physik* 61, 149, 1930.

[4] S. Smith, Phys. Rev., 36, 1, 1930.

[5] J. E. Mack, *Phys. Rev.* 34, 17, 1929.

# A GENERALIZATION OF A WELL-KNOWN THEOREM

By T. Vijayaraghavan

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The theorem known as Vivanti-Borel-Dienes-Theorem[1] asserts that if $\Sigma\ C_n\ z^n$ has unit radius of convergence, and the $C$'s belong to a *Winkelraum* whose angle is less than $\pi$ then $z=1$ is a singular point of $f(z)$ where $f(z) = \Sigma C_n\ z^n$. It may perhaps be a little interesting to know whether the *Winkelraum* referred to above can be replaced by a more general domain $D$. In the following theorem such a domain $D$ is indicated; indeed, in a sense, it is a "best possible" $D$.

THEOREM.—*Suppose that* $z=x+iy$, $\delta$ *and* $\triangle$ *are any two positive numbers, and* $\theta$ *is any angle; let* $D_1=D_1(\delta, \triangle)$ *denote the domain which consists of the half plane,* $x \geqq \delta$, *together with the region* $|y|^{\triangle} \leqq x$ *for* $0 \leqq x \leqq \delta$. *Let* $D=D(\delta, \triangle, \theta)$ *be the domain that* $D_1$ *occupies when it has been rotated about the origin through an angle* $\theta$. *If now* $f(z) = \Sigma C_n\ z^n$ *and the* $C$'S *are such that they belong to a* $D$, *and the Radius of Convergence of the power series is unity, then* $z=1$ *is a singular point of* $f(z)$.

## Reference

[1] L. Bieberbach, *Lehrbuch Der Funktionentheorie*, Vol. 2, (1st Edition), p. 280.

## ON SOME EXPERIMENTS WITH IODINE VAPOUR

### By G. R. Toshniwal

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The experiments described below were undertaken with the specific purpose of affording direct experimental verification of Franck's theory[1] of photo-dissociation of halogen molecules; though the experiments have not been successful, some results of very perplexing nature have been obtained, which may lead to some unexpected discovery.

It has been known from a long time that $I_2$-vapour at ordinary temperatures shows a band absorption beginning from $\lambda 4995$ A. U. extending up to $\lambda$ 3400 A. U. The width of continuous absorption on both sides of $\lambda 4995$ A. U. depends upon the total vapour content. Similar band and continuous absorption is also shown by the other halogens. The continuous absorptions have been explained by Franck in the following way :—

Iodine molecule in its normal state is supposed to consist of two iodine atoms in the lowest energy state, i.e., $5 p^5 \cdot {}^2P_{\frac{3}{2}}$ The next higher metastable state is $5p^5 \, {}^2P_{\frac{1}{2}}.$ When light falls on a normal molecule, they act only on one of the electrons of the molecule so that ${}^2P_{\frac{3}{2}}$ -state is excited to the next higher state, viz., the ${}^2P_{\frac{1}{2}}$ state. The excited molecule is now composed of two atoms of which one is

in the $^2P_{\frac{3}{2}}$ and the other in the $^2P_{\frac{1}{2}}$-state. Franck postulates that we get the bands when the excited light is just sufficient to excite the atom from $^2P_{\frac{3}{2}}$ to $^2P_{\frac{1}{2}}$-state, and thereby possesses sufficient energy to dissociate it. The situation is clearly explained by the Franck-Condon diagram showing the variation of potential energy with the distance between the component atoms in the normal and the excited states as explained in Fig. 1.
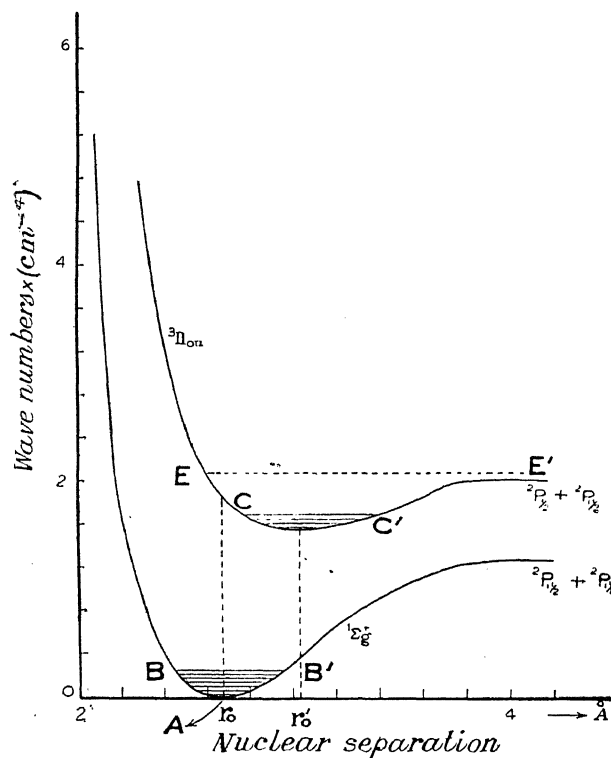


Fig. 1.—Franck-Condon diagram for energy states of the $I_2$-molecule.

The abscissæ represents distance $r$ and the ordinates the potential energy $U(r)$. The minimum value of $U(r)$ is taken as zero. The curve (1) shows the value of $U(r)$ when the component atoms are in the $^2P_{\frac{3}{2}}$-state. In this case[2] $r_0 = 2\cdot66 \times 10^{-8}$cms. and $\omega'' = 214\cdot6$ cm.$^{-1}$

The lowest point A in curve (1) corresponds to the lowest vibration state $n'' = 0$. The upper points B B' corresponds to the excited vibrational states in which $n'' > 1$

Curve (2) represents U (r) when the component atoms are in the $^2P_{\frac{3}{2}}$ and $^2P_{\frac{1}{2}}$ -states.   In this case

$$r_0 = 3{\cdot}08 \times 10^{-8} \text{ cm. and } \omega' = 127{\cdot}5.$$

Here also the lowest point corresponds to the lowest vibration state of the excited $n'=0$. The higher points CC' correspond to higher vibration states in which $n'>1$.

When light falls on the atom, the representative point may change from A to any point in curve (2).   The most probable point of shift will be C, where C has the same nuclear distance $r$ as A.   But the molecule may change to any point lying on the curve (2).   If such a point C lies above the line E E' which form the asymptote to the curve (2), iodine gets dissociated and the absorption now becomes continuous.   If C be below E E 'we get band absorption.

According to this theory the beginning of absorption indicates the photodissociation of the molecule of iodine into $^2P_{\frac{3}{2}}$ and $^2P_{\frac{1}{2}}$ -states.   The truth of this theory is proved by the correctness of the mathematical relation

$$h\nu = D_{I_2} + {}^2P_{\frac{3}{2}} - {}^2P_{\frac{1}{2}}$$

We know from the spectroscopic data that

$$h\nu = 56{\cdot}95 \text{ k cal. and } {}^2P_{\frac{3}{2}} - {}^2P_{\frac{1}{2}} = 21{\cdot}6 \text{ k cal.}$$

Thus $D_{I_2}$ comes out to be 35.35 k. calories.

This value is in agreement with Bodenstein and Starck's[3] value, which they obtained by direct experimental study of the degree of dissociation of $I_2$ at different temperatures by the application of the law of mass action. If Franck's theory be correct, then as a result the illumination of $I_2$ by light of wavelength less than $\lambda$ 4990, a good fraction of molecules should be expected to split up into atoms in $^2P_{\frac{3}{2}}$ and $^2P_{\frac{1}{2}}$ -states, and the number in the $^2P_{\frac{1}{2}}$ -state should be equal to the number in the $^2P_{\frac{3}{2}}$ -state

The simplest way of experimentally demonstrating this is by studying the absorption spectrum of $I_2$ vapour irradiated by light of wavelength less than $\lambda$ 4990.   Irradiated iodine gas should show absorption of lines arising from $^2P_{\frac{3}{2}}$ and $^2P_{\frac{1}{2}}$ -states.

According to the classification of $I_2$ arc lines by Turner,[4] Evans[5] and Deb,[6] the fundamental lines have been arranged as follows (Table 1) :

According to Table 1 given below, irradiated $I_2$ vapour is expected to show absorption of $\lambda$1830 and $\lambda$ 2062 lines respectively in the quartz region.   Of this

$\lambda 1830$ indicates the presence of Iodine in $^2P_{\frac{3}{2}}$-state, and $\lambda 2062$ indicates the presence of iodine in the $^2P_{\frac{1}{2}}$-state. In the existing literature several such experiments

*Table 1*

| $5p^5$ <br><br> $5p^46s$ | $^2P_{\frac{3}{2}}$ | $^2P_{\frac{1}{2}}$ |
|---|---|---|
| $^2P_{\frac{5}{2}}$ | 54632 <br> $\lambda 1830\cdot4$ | |
| $^2P_{\frac{3}{2}}$ | 56089 <br> $\lambda 1782\cdot9$ | 48494 <br> $\lambda 2062\cdot1$ |
| $^4P_{\frac{3}{2}}$ | 60885 <br> $\lambda 1642\cdot5$ | 53293 <br> $\lambda 1876\cdot4$ |
| $^2P_{\frac{1}{2}}$ | 61809 <br> $\lambda 1617\cdot9$ | 54216 <br> $\lambda 1844\cdot5$ |
| $^4P_{\frac{1}{2}}$ | 66342 <br> $\lambda 1507\cdot3$ | 58744 <br> $\lambda 1702\cdot3$ |

are reported. Turner and Samson[5] report that they were able to get the absorption of $\lambda 1830$ and other lines corresponding to the $^2P_{\frac{3}{2}}$-state at a temperature of 20°C. When the same light was passed through $I_2$ vapour at 20°C the absorption was found to be intensified when $I_2$ vapour was irradiated with light from the carbon arc. But their experiments are rather indirect and indecisive, for it is difficult to see how vapour at 20°C in the absence of irradiation can be sufficiently dissociated to give absorption of the atomic line $\lambda 1830$. To show this, we calculate the degree of dissociation of vapour at 20°C from Gibson and Heitler's[7] formula; we find that

$$K_p = \frac{4x^2}{1-x^2}\,p = 1\cdot23 \times 10^{-17}$$

and since the dissociation is extremely slight, we put $1-x^2=1$, and obtain

$$4\,x^2\,n\,k\,T = 1\cdot23 \times 10^{-17}.$$

$$\therefore x = 1 \times 10^{-10}$$

$$\left[\text{since } n = \frac{p}{kT} = \frac{2\cdot5 \times 10^{-1} \times 1330}{1\cdot36 \times 10^{-16} \times 293} = 8 \times 10^{15}\right]$$

$x$ represents the degree of dissociation at 20°C due to heat alone. But the pressure of Iodine at 20°C is about 0.25 mm. of mercury whence the number of iodine molecules per c.c. is $8 \times 10^{15}$ as calculated above. Thus the number of free atoms per c.c. is

$$n x = 8 \times 10^{15} \times 10^{-10} = 8 \times 10^{5}.$$

This number is quite insufficient to show any absorption $I_2$ vapour.

Let us therefore carefully consider the experiments reported by Turner and Samson.[*] Discharge was passed through a tube containing iodine, which emitted the arc lines of iodine including $\lambda 1830$, and $\lambda 2062$. This light was passed through a second vessel containing iodine at .03 mm. pressure.

They found that on passing through the absorption chamber, $\lambda 1830$ was absorbed feebly, but $\lambda 2062$ was not absorbed at all. But when the latter was illuminated by light from a carbon arc $\lambda 1830$ was still more strongly absorbed, while even in this case there was no trace of absorption of $\lambda 2062$. From this, they concluded that the increased absorption of $\lambda 1830$ was due to photo-dissociation of $I_2$ vapour, a conclusion with which it is difficult to agree, since no absorption of $\lambda 2062$ was observed.

The experimental results are difficult to understand. According to the calculation given above, $I_2$ at 20°C has only $8 \times 10^5$ free atoms per c.c. and hence it cannot show any absorption of $\lambda 1830$. The absorption observed by Turner must have been due to some other cause. It may have arisen from the fact that, even in the first experiment, as $I_2$ in the absorption chamber is subjected to continuous light from A, including emission lines between $\lambda 4900$ and $\lambda 4000$, photodissociation of $I_2$ is produced. The absorption of $\lambda 1830$ must be due to iodine atoms produced in this way and when in the second experiment, the absorption chamber was subjected to light from carbon arc, photodissociation was still more intensified, hence $\lambda 1830$ was still more strongly absorbed.

But this does not explain why $\lambda 2062$ is not at all absorbed in any of the experiments If the production of atoms was due to photodissociation, $^2P_{\frac{1}{2}}$ atoms which are responsible for the absorption of $\lambda 2602$ must have been produced in equal numbers with $^2P_{\frac{3}{2}}$ atom which is responsible for the absorption of $\lambda 1830$), hence it is difficult to understand why $\lambda 2062$ will not be absorbed in either case.

The difficulty may be explained by the assumption that $^2P_{\frac{1}{2}}$ atoms after being produced are almost immediately reduced to the $^2P_{\frac{3}{2}}$ state by collisions of the second type with the gas molecules present. Anyhow Turner and Samson have not been able to demonstrate the truth of Franck's theory. The same experiment was performed by Sponer and Watson[*] and they too report a negative result. The experiment was undertaken by me with a view to attack the problem directly and as the experimental procedure is somewhat different, it is described in detail below. I should mention here that when my experiments were started I was ignorant of the existence of these experiments.

## Experiment

The apparatus used in carrying out the present experiments was very simple. Continuous light from a hydrogen discharge tube was passed through a pyrex glass tube about 12 cm. long which was filled with iodine vapour coming from a bulb attached to it. The absorption tube was illuminated by means of carbon arc fed with metallic zinc. Zinc was used as it emits a strong triplet λ.

Both Schumann plates and ordinary plates sensitised by means of 0·5% solution of yellow vaseline in petrolium ether were used for photographing the absorption spectra. It was found that no trace of absorption of λ2062 could be seen in any case, but two new absorption lines were detected, the wavelengths of which were found to be λ2012 ± 1 A and λ1969 ± 1 A. respectively. These two lines appeared persistently in all plates whether the absorption chamber was irradiated by carbon arc or not. λ1969 was much fainter than λ2012. In order to see whether these lines belonged to iodine present in the tube, another experiment was performed in which a mild discharge was passed through iodine contained in the absorption tube, which was provided with nickel electrodes. It was found that both these lines could also be obtained in the emission spectrum. On consulting the literature, it was found that Füchtbauer, Weibel and Holm[10] obtained two lines, whose wavelengths he gave as 2016 and 1972·3 Å.U. in a weak condensed discharge through iodine vapour. In addition to these he got various other lines between λ 2062 and λ 1972. The two lines obtained by me seem to be identical with Füchtbauer's λ2016 and λ1972, but the large discrepancy in wavelengths is inexplicable unless one of us has committed a grave error in measuring the lines.

Now these lines neither belong to silver, nickel or chlorine nor are air lines or principal lines of any element. The only alternative seems to be that they are due to the iodine-atom or iodine molecule or to some impurity present in the sample of iodine.

That these lines cannot be due to $I_2$ molecule can be judged from the following reasons. The wavelength does not correspond to any of the band lines registered by Oldenberg[11] in this region. It may also be mentioned here that no band absorption was obtained in this region as reported by Kimura and others,[12] which may be due to the fact that the amount of iodine vapour present in the tube was very small as the temperature of the side bulb was maintained at 0°C.

Oldenberg bands correspond to the transition form $5p^5$ $^2P_{\frac{3}{2}}$ to $5p^4$ $6s$ $^4P_{\frac{5}{2}}$ -states of one of the component atoms. The bands which are obtained in the λ2000 region are due to the fact that by heat the $I_2$-molecule in the fundamental state is raised to higher vibrational states, so that the bands shift towards the longer wavelength. The lines observed cannot possibly be identical with a narrow band absorption. This is further disproved by the fact that difference between the two lines observed on my plate is about $\triangle \nu = 1086$ and has no relation to the fundamental difference $\triangle \nu = 213·6$ of the iodine molecule.

The next possibility is whether they can be due to any possible mode of transition of iodine atom. The fundamental state can pass by absorption to the states. as mentioned below :

$$(5 s^2) (5p^5) \; ^2P_{\frac{3}{2}}, \; ^2P_{\frac{1}{2}} \longrightarrow 5s^2 \; 5p^4 \; 6s \; ^4P, ^2P$$

$$\longrightarrow 5s^2 \; 5p^4 \; 5d \; ^4D \; ^2D \ldots$$

$$\longrightarrow 5s \; 6p^6 \; ^2S$$
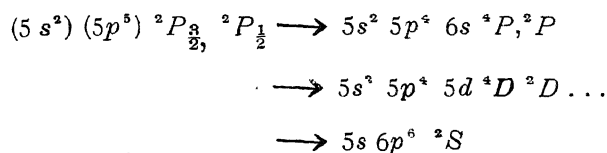
As regards the value of the $5d$ -terms a comparison with the values of the corresponding terms in the neighbouring atoms from indium to cæsium shows that their value cannot exceed 17000 (The value of cs $5d \; ^2D_{\frac{3}{2}}$, $_{\frac{5}{2}}$ are equal to 16807 and 16905 respectively). Hence lines due to the transition $5p^5 \longleftarrow 5p^4 \, 5d$ will lie in the neighbourhood of $\lambda$ 1500, for the value of $5p^5 \; ^2P_{\frac{3}{2}} = 8500$ and $5p^5 \; ^2P_{\frac{1}{2}} = 77000$. Similarly the inner transition lines are also excluded because the value of $^2S_{\frac{1}{2}}$ in such cases will be very small.

The only suggestion which can be made at this stage, but which is rather difficult to establish, is that they are due to element No. 85, which belongs to the halogen group. A number of investigators report the discovery of this element, but nothing seems to be certain. It is quite possible that in the sample of $I_2$ this element is present in small proportion, and has not been separated by chemical methods used in the preparation of iodine. Three other samples of iodine were found to give $\lambda$ 2012 In this connection, the case of discovery of Hafnium may be cited. Hafnium (72) is always associated with its analogue Zirconium (40), and lines of Hf were always found in the Zr-spectrum, but were disregarded as being merely due to impurities. It was only after Bohr indicated that Hf would have properties similar to Zr (40) and Hevesy and Coster established its existence by X-ray methods in Zirconia minerals, that the impurity lines in Zr-spectrum were traced to Hf (72). The spectrum of this element (85) will be quite similar to iodine and these two lines obtained by me may form the fundamental lines of the new element corresponding to the following transition.

*Table 2*

| $7p^5$ | $^2P_{\frac{3}{2}}$ | $^2P_{\frac{1}{2}}$ |
|---|---|---|
| $7p^4 8s$ | | |
| $^4P_{\frac{5}{2}}$ | 2016 | |
| $^4P_{\frac{3}{2}}$ | 1970 | |

The facts of the experiments are not at least against such a hypothesis.

My thanks are due to Prof. M. N. Saha, for his kind interest throughout the work.

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# ON THE ABSORPTION SPECTRA OF ALKYL HALIDES

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The explanation of the absorption spectra of the Alkyl Halides has received considerable attention from various authors, *e.g.* Herzberg and Scheibe[1], Iredale and Wallace[2], and Iredale and Mills[3] in recent years. In the region of quartz they have been found to possess no band absorption but there is a continuous absorption beginning from a long wave limit. It is well known that by an extension of Kratzer's theory of diatomic molecule, when about to dissociate, Born and Franck have shown in the case of ionic compounds like the halides of the alkalis, that the passage of continuous light through the vapours of these molecules results in photochemical dissociation into alkali and halogen, giving a continuous absorption

$$NaCl + h\nu = Na + Cl \qquad \ldots \qquad \ldots \qquad \ldots \qquad (1)$$

It is supposed as already mentioned that normally NaCl exists as $Na^+$ and $Cl^-$ and the primary act of light is to transfer one electron from Cl to Na, resulting in photochemical dissociation of the compound into two neutral atoms. Here $h\nu$ can be obtained with the aid of a Born cycle as

$$h\nu = Q + \tfrac{1}{2}D_{Cl_2} + L_{Na} - L_{NaCl}$$

Where 
$$Q = \text{Heat of formation of NaCl}$$
$$D_{Cl_2} = \text{Heat of dissociation of Cl}$$
$$L_{Na} = \text{Heat of sublimation of Na}$$
$$L_{NaCl} = \text{Heat of sublimation of NaCl.}$$

In the following table is reproduced the values obtained by Herzberg and Scheibe[1] for certain of the Methyl Halides.

*Table 1*

| Molecule | Calculated limited (k cal.) | Observed beginning and complete extinction (k cal.) | Surplus energy after accounting for the excitation of Halogen. |
|---|---|---|---|
| $CH_3I$ | 44 | 102 (112) | 37 (46) |
| $CH.Br$ | 59 | 123 (143) | 54 (76) |
| $CH.Cl$ | 73 | 151 (164) | 76 (89) |

The second column gives the calculated energies of C–Cl bond. These values are given by Eucken (Lehrbuch der Chemische Physik) and have been calculated in the following way :—

Heat of formation of $CH_4$ = 368 k cal,

Heat of formation of $C_2H_6$ = 623 „

These give us four C–H bonds in $CH_4$, *i.e.*, $4x$ = 368 k cal

so that $x$ = 92 k cal

that is, energy of C–H bond      = 623 „

In the case of $C_2H_6$ we have six C–H bonds + one C–C bond = 623 k cals.

value of C–C bond      =    71 k cals.

For $CH_3Cl$ the heat of formation is 349 k cals, so that we get as the energy of the C–Cl bond as

$$349 - 3(C-H) = 349 - 276$$
$$= 73 \text{ k cal. and similarly for the others.}$$

As can be seen from the table that Herzberg and Scheibe[1] got as their beginning of absorption for $CH_3Cl$ as 151 k cals, giving a surplus of 76 k cals, over the calculated value which they could not account for. They discard any possibility of the separation of the H-Atom from the $CH_3Cl$ molecule due to the absorption of light, as according to their calculations the limit of absorption extends towards the shorter wavelength side, and the decision arrived at was that $CH_3Cl$ broke up into $CH_3$ and Cl like NaCl—a process which does not account for the surplus energy. Even the excitation energy of the Halogen atom could not make up for the excess of energy. The energy states of $CH_3$ being unknown, excitation energy of $CH_3$ could not be added to the values.

The absorption tube used by Herzberg and Scheibe was only 10 cms. long and the pressures they used were of the order of 1/10 to 1/100 of an atmosphere. It might be said that these lengths and pressures are rather arbitrary as by no theory any hard and fast values have been provided for these. It has been found from experiments conducted in this laboratory that a length of 100 cms. with a pressure of an atmosphere gives quite a different long wave limit of continuous absorption by direct measurement, but direct measurement too does not suffice.

Other attempts are by Iredale and Wallace and Iredale and Mills. These workers also used arbitrary lengths of absorption tubes and pressures, and have found the long wave limit of absorption directly by taking the microphotogram of the plates. Iredale and mills suppose tetravalent C as in the case of $CH_4$, $C_2H_6$, $CH_3Cl$ etc. exists in the $^5S$ state. We have six electrons in C, so that we place them accordingly in the following manner in different shells

$1s$
$(2)$

$2s$      $2p$
$(2)$      $(2)$
$3s$      $3p$      $3d$

If one electron is allowed to travel to $(3s)$ we get as our normal state as $^3P$ whereas a transfer of one electron from $(2s)$ to $(2p)$ shell gives us

$(2p)^3$            $^3S$

$(2s)(2p)^3$        $^5S$     $^3S$

The difference in energy between divalent C $(^3P)$ and $(^5S)$ has been calculated with the aid of some thermochemical data to be 97 k cal.

$$C(^3P) = C(^5S) - 97 \quad \text{k cals.}$$

in which case $^5S$ is a deeper state. For this state, or its energy value there is yet no evidence from spectroscopic analysis. Then, the authors have calculated the value of C–H bond and from that the value of C–Br bond. But they have made use of the values 139 as heat of sublimation of C and 117 as the heat of dissociation of Oxygen-values which have been superseded by recent more correct values.[4] With these values the value of the difference of C $(^5P)$ and C $(^5S)$ have been recalculated, and comes out to be 134 k cals. The result is that the calculated and experimental values of Iredale and Mills' are found to vary very greatly. And also in the latter case the value of one 1 C–C bond has been lost sight of.

Mr. N. K. Saha[5] has calculated the value of the C–Cl bond in $CCl_4$ on the lines of Iredale and Mills[3] and it has been found that the results do not tally with the more correct values of Dutta and Saha[6] calculated from a Born cycle.

## EXPERIMENT

The absorption chamber was simply a tube 100 cms. in length with quartz windows, and provided with two side tubes. With one of these side tubes a glass bulb was connected in which the liquid was placed. The other was connected with a pump through a manometer. After evacuation a certain pressure of the vapour could be obtained by turning the connecting stop-cock. The source of continuous spectrum was H-tube run by a 2KW transformer, and for comparison Cu spectrum was taken in each of the plates. An $E_3$, Quartz spectrograph was used.

Microphotograms of the plates were taken by means of a Zeiss Microphotometer belonging to the Science College, Patna, and here I must thank Prof. A. T. Mukherji for his kindly allowing us to use the apparatus. My thanks are also due to Mr. M. S. Desai of this department for the trouble of taking the microphotographs for me.

The calculation and measurement of the longwave limit was done in the following manner. Along the different wavelengths for each of the plates, the ratio of the intensities of the continuous and absorption spectrum at certain pressure, with the intensity of the continuous as 100 was calculated and plotted with wavelength as abcissa. The curves were found to touch the abcissa at one wavelength for each substance giving the beginning of absorption. For example

in the case of $CH_3Cl$, a visual observation of the limit as 2100 was extended to 2200 from the curves.

It might be supposed that the primary act of light is to break the C–Cl bond requiring the energy corresponding to 2200, $i.e.$, 130 k cals. Other substances tried were $C_2H_5Cl$, normal $C_5H_7Cl$, and normal $C_4H_9Cl$, but in all these cases no perceptible differences were found for the value of the C–Cl bond.

In conclusion I wish to express my thanks to Prof. M. N. Saha, for his kind interest and guidance during the course of the work.

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# ON THE DETERMINATION OF THE VAPOUR PRESSURES OF ZINC BROMIDE

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## INTRODUCTION

' *Vapour pressure determinations are of great practical value, not least for the molecular ray technique itself but undoubtedly the most important use to be made at the present time of accurate vapour pressure data is in establishing the validity of certain very interesting points in the theory of thermodynamics* ' (Molecular Rays by Ronald G. J. Fraser, p. 176). We may add that it is also necessary for testing the modern theories of chemical binding.

The knowledge of the vapour pressures of solids enables us to determine the latent heat of evaporation of the substance. In the present case the latent heat of zinc bromide was required to test the new theory of continuous absorption of halides of divalent atoms, such as zinc.

The theory of absorption of the halides of monovalent elements has been satisfactorily given by Born and Franck,[1] but very little work has been done on the halides of the poly-atomic elements. Attempt has been made by Dutta and Saha[2] to put forward a theory of absorption of the halides of multivalent elements, but the theory yet requires more definite confirmation from experimental results.

In the case of the halides of monovalent elements, if $\lambda$ be the beginning of absorption on the longer wavelength side, $h\nu$ exactly corresponds to the value,

$$R = \frac{N\,h\nu}{J} = \frac{286000}{\lambda} \qquad \qquad \cdots \qquad \cdots \quad (1)$$

$$\text{or } \lambda = \frac{286000}{R}$$

and

$$R = Q + \tfrac{1}{2}D_{x_2} + L_M - L_{MX}$$

The theory, in its present state says that in the case of the halides of multi-valent elements $MX_n$ the beginning of absorption $\lambda$ can be expressed as

$$\lambda = 286000 \times \frac{n}{R} \qquad \cdots \qquad \cdots \qquad \cdots \quad (2)$$

In the case of halides of di-valent elements $n = 2$ and

$$R = Q + D_{x_2} + L_M - L_{MX_2}$$

The purpose of the present work is to determine the latent heat of $ZnBr_2$ in order that equation (2) may be accurately tested.

## METHOD

The method used is that of effusion of vapour through a small hole, at an extremely low pressure, when heated at a constant temperature, for a definite time. The method was first suggested by Knudsen and largely used by Egerton, Harteck and others.* From the kinetic theory of gases we obtain the relation,

$$p = \frac{m}{A\,t} \sqrt{\frac{2\,R\,T}{M}} \qquad \cdots \qquad \cdots \qquad \cdots \quad (3)$$

Where $p$ is the vapour pressure at $T^\circ K$, $m$ is the mass of the effused vapour, $t$ is the duration of effusion in seconds, A is the area of the hole, M is the molecular weight of the substance, and $R = 8\cdot3 \times 10^7$. It must be noted that the above relation holds good only when the temperature is such that the molecules neither dissociate nor associate.

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* See note at the end of the paper.

## EXPERIMENT

The apparatus used is shown in Figure 1.

*The apparatus.* — The vapour pressure apparatus of transparent quartz was made according to our design as in the figure. It was kept inside an electrical
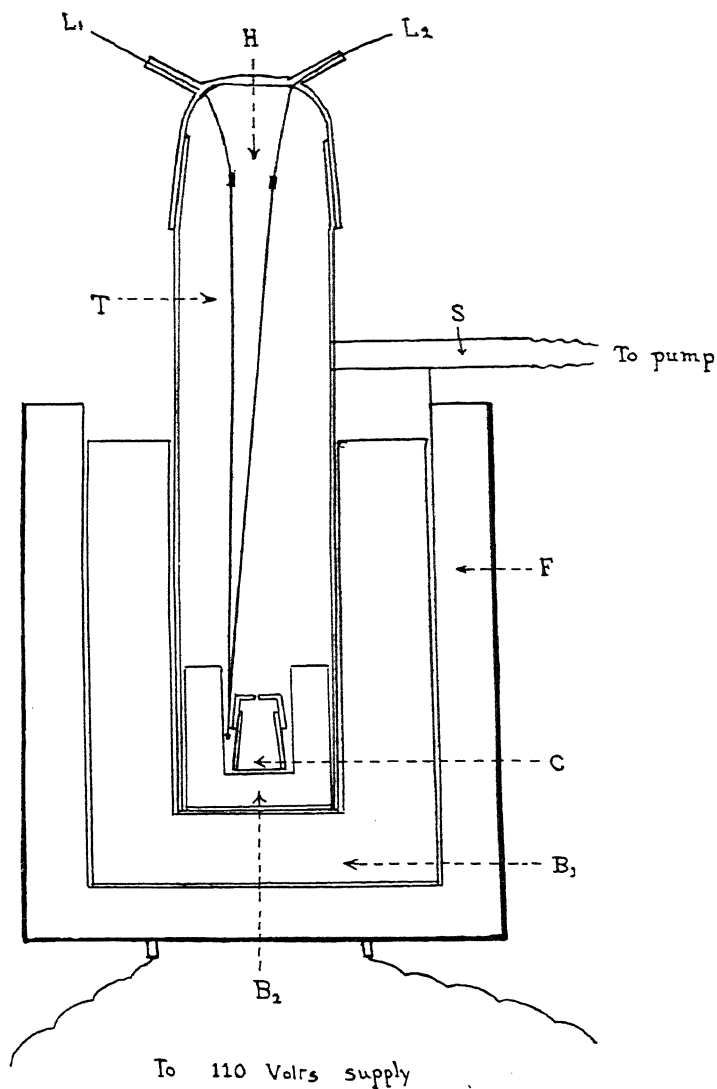


Fig. 1

furnace F, within a hole cut in the brass block B$_1$ which when heated ensures uniformity of temperature.

Anhydrous zinc bromide supplied by Merck was weighed and kept inside a quartz crucible C, having a fine hole in the lid. The crucible was put inside a cylindrical thick copper block $B_2$ and introduced inside the apparatus. The junction of a copper-constantine thermocouple was introduced inside the copper block $B_2$, by the side of the crucible. The thermojunction was put inside quartz tubing and protected from the effects of the vapour inside the apparatus.

The quartz apparatus consists of mainly three parts: the main tube T, the ground head H, and the crucible C. (i) The main tube T is about 40 cms. long and has a diameter of 4 cms. The wall is about 1·5 mms. thick. The bottom is flat and the mouth conical in shape, and ground accurately. It has a side tube S for the connection to the high vacuum pump. (ii) The head H is conical and also accurately ground to fit vacuum tight on the tube T. It has two thermocouple leads $L_1$ and $L_2$ at the top. (iii) The crucible is also conical of about 2 cms. height having a ground cover with a fine hole in the centre of the cover.

*The Furnace.*—Uniformity of temperature is attained by means of two metallic blocks $B_1$ and $B_2$. The furnace was heated electrically from a 110 volts D. C. supply. The current was kept constant by adjusting the resistance with the aid of a very fine rheostat. The maximum current which the furnace could bear was 5 amps.

*Vacuum.*—Special care was taken to attain very high vacuum. A 3-stage mercury diffusion pump was used as the primary pump and a Max Kohl's oil pump was used as secondary pump. Before connecting the main apparatus, the available vacuum was tested by means of a discharge tube, and the conditions were so perfect that no discharge stage was soon obtained, and the vacuum could balance a spark gap of about 5 to 6 inches. In order to avoid the mercury vapour from diffusing into the main apparatus the conical end of the pump was surmounted by an accurately fitting steel tube 24 inches long, which was surrounded by a jacket. The jacket was filled with ordinary freezing mixture. This ensures a vacuum of very high order of about $10^{-5}$ mms. and prevents diffusion of mercury completely, as is shown by the fact that no mercury lines are observed when discharge is passed through the discharge tube.

*Temperature.*—The temperature was measured by means of a well prepared copper-constantine thermocouple. The junctions of the thermocouple were welded electrically in a carbon arc. The colder junction was kept at zero degree (in melting ice), and the thermal voltage was read by means of an accurate millivolt-meter reading up to 0·5 mv. Special care was taken to avoid the effect of the vapour on the thermojunction by protecting it inside a quartz tube. The inner junction was introduced inside as near the crucible as possible. The thermocouple was first calibrated by putting it inside fixed temperature baths. It gave values almost identical with those given by Landolt and Börnstein.[*] The temperatures at which

the experiment was carried out was below the temperature of dissociation of zinc bromide.

*Time* —Time was counted by means of a chronometer reading accurately up to half a second, which was quite sufficient for the purpose. In order to start counting just when the experiment began, and stop counting when the experiment stopped, the following procedure was adopted. The substance was introduced inside and the apparatus evacuated. After perfect evacuation a small pressure of nitrogen was introduced inside the heated furnace. As long as the furnace contains some gas no effusion takes place. When the thermocouple shows a constant reading the nitrogen was pumped out, the counting was commenced just when soft X-ray stage was reached. Before stopping the experiment, nitrogen was introduced in the same way.

*Area.*—The area of the hole is a very important determination and requires great accuracy in its measurement. The following method was devised for the accurate measurement. The top surface of the lid of the crucible was projected on a sheet of graph paper by the help of a very powerful epidiascope. A fine scale, accurately graduated in half millimeters, was also placed by the side of the hole. This was meant for the determination of the linear magnification. The inner border of the image of the hole was traced on the squared paper, and the area was determined by counting the number of the squares covered by the image of the hole. The true area was obtained by dividing the area so obtained by the square of the linear magnification. Different magnifications were used by changing the distance of the screen and the average value of A was determined.

*Mass.*—The mass of the vapour effusing out was measured by the method of differences. The empty crucible was repeatedly heated in vacuum till it gave a constant weight. The salt was put inside and weighed before the experiment was commenced and again at the end of the experiment. The loss of weight gives us the mass which has effused out. A very fine chemical balance was used for weighing

## RESULTS

In equation (3) the constant quantities are, M the molecular weight of zinc bromide $= 225 \cdot 2$. The area of the hole is $0 \cdot 0263$ square cms. The other quantities are given in the following Table 1.

F. 3

*Table 1.*

| Mass in gms. m | Time of heating T sec. | Thermo-volt M. V. | Temp °C. | P (mm.) calculated |
|---|---|---|---|---|
| ·1368 | 1500 | 13·0 | 208 | ·0933 |
| ·0673 | 1260 | 14·1 | 316 | ·1382 |
| ·2960 | 1200 | 16·6 | 346 | ·2669 |
| ·7423 | 1800 | 17·5 | 360 | ·4211 |
| ·5126 | 900 | 18·2 | 374 | ·6832 |
| ·8264 | 900 | 19·0 | 389 | 1·0280 |
| ·9472 | 720 | 19·8 | 400 | 1·6090 |

## THE VAPOUR PRESSURE EQUATION

The results which have been obtained could be expressed in the form of an equation similar to one given by Knudsen[5] for mercury.

Starting from the Clausius' equation we get

$$\lambda = R\, T^2\, \frac{d\,ln\,p}{d\,T}$$

and $\lambda = \lambda_0 - (C - C_p)\,T$,    where C is the molecular heat of the vapour at constant pressure, whence

$$ln\, p = -\frac{\lambda_0}{RT} - \frac{(C - C_p)}{R}\,\log T + k$$

but assuming

$$C - C_p = 3\,R - \frac{5}{2}\,R = \frac{R}{2}$$

$$p = k\,.\,T^{-\frac{1}{2}}\,.\,C^{-\lambda_0/RT}$$

This gives

$$\log_e p = -\frac{\lambda_0}{RT} - \tfrac{1}{2}\log_e T + \log_e k$$

$$\log_{10} p = -\frac{\lambda_0}{2\cdot3\,RT} - 0\cdot5\,\log_{10} T + k^1 \quad \ldots \qquad \ldots \quad (4)$$

This is of the form,

$$\log p = -\frac{A}{T} - 0\cdot5\,\log T + B$$

Table 2 gives the values of log $p$ and log T and graph I shows the actual graph between log $p$ and log T.

*Table 2.*

| Temp °C | Temp °K | $\log_{10}$ T | Press. mms. | $\log_{10}$ P |
|---------|---------|---------------|-------------|---------------|
| 280 | 553 | 2·7427 | 0·0933 | −1·0302 |
| 316 | 589 | 2·7701 | 0·1382 | −0·8595 |
| 346 | 619 | 2·7917 | 0·2669 | −0·5736 |
| 360 | 633 | 2·8014 | 0·4211 | −0·3756 |
| 374 | 647 | 2·8109 | 0·6832 | −0·1658 |
| 389 | 662 | 2·8209 | 1·0280 | 0·0342 |
| 400 | 673 | 2·8280 | 1·6090 | 0·2063 |

Further we have the equation,

$$\log p = -\frac{A}{T} - 0\cdot5 \log T + B$$

Where

$$A = \frac{\lambda o}{2\cdot3R} \qquad \ldots \qquad \ldots \qquad \ldots \quad (5)$$

Now from our experimental data we shall evaluate the constants of the equations, *viz.*, A and B. We have,

| T°A | log T | log P |
|-----|-------|-------|
| 633 | 2·8014 | −·3756 |
| 662 | 2·8209 | ·0342 |

Substituting this data and solving the equations we get,

$$A = 6063\cdot0$$
$$\text{and} \quad B = 10\cdot6041$$

Thus the vapour pressure equation for zinc bromide, between the temperatures 300°C to 400°C is

$$\log p = \frac{-6063}{T} - 0\cdot5 \log T + 10\cdot6041 \quad \ldots \qquad \ldots \qquad \ldots \quad (6)$$

## THE LATENT HEAT OF EVAPORATION

From the equation (5) we have

$$A = \frac{\lambda_0}{2 \cdot 3 \, R}$$
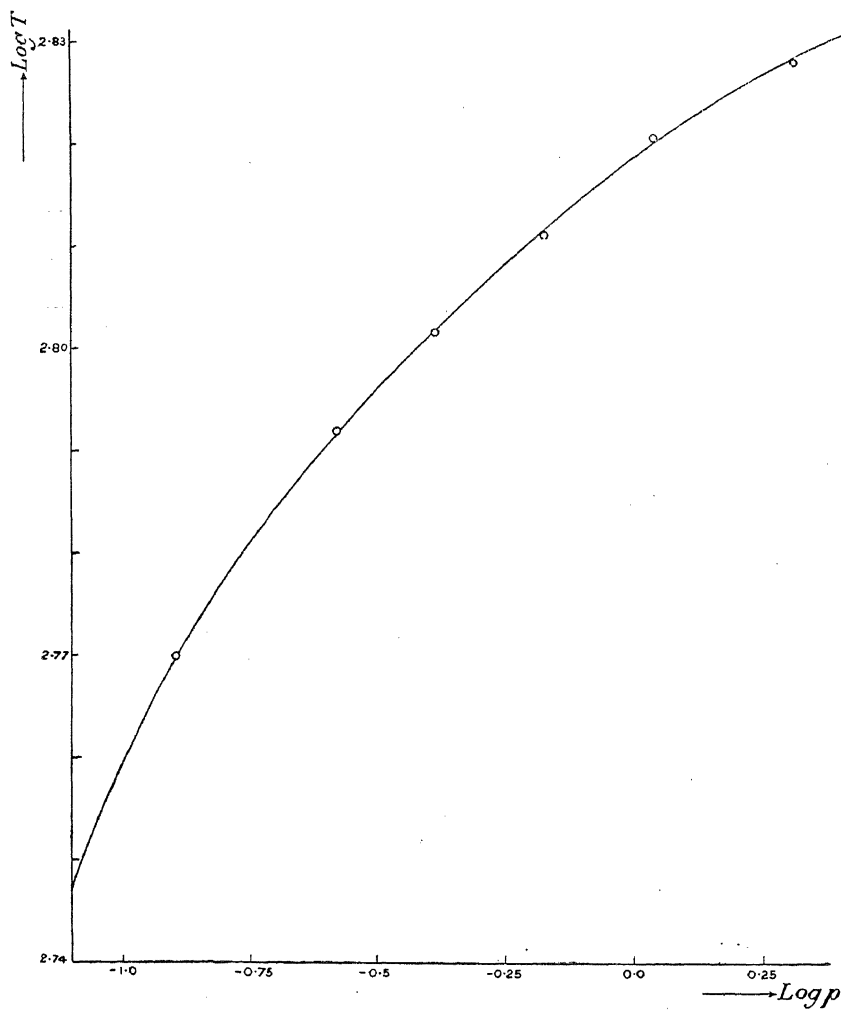


Fig. 2

$\therefore$   Latent heat $\lambda_0 = 4 \cdot 554 \, A$

$\qquad\qquad\quad = 27600$ calories

or $\qquad\qquad = 27 \cdot 6$ k. cal.

## SUMMARY

In the present paper the vapour pressures of Zn Br$_2$ (anhydrous) are determined over the range of temperatures from 280°C to 400°C by the method of effusion of the vapour from a small hole the values abtained are

| T°C. | $p$ (mm.) | |
|------|-----------|---|
| 280 | ·0933 | |
| 316 | ·1382 | |
| 346 | ·2669 | |
| 360 | ·4211 | ... (I) |
| 374 | ·6832 | |
| 389 | 1·0280 | |
| 400 | 1·6090 | |

The graph drawn between the values of log $p$ and log T shows curve according to the equation

$$\log p = -\frac{A}{T} - 0\text{·}5 \log T + B$$

where

$$A = \frac{\lambda_0}{2\text{·}3\,R}$$

The constants A and B are determined by making use of the experimental data and the equation is evaluated to be,

$$\log_{10} p_{(mm)} = -\frac{6063}{T} - 0\text{·}5 \log_{10} T + 10\text{·}6041 \qquad \ldots \qquad \ldots \quad (II)$$

Further from the value of A ( = 6063 ) the latent heat of evaporation of zinc bromide is evaluated to be,

$$L = 27\text{·}60 \text{ k. cal.} \qquad \ldots \qquad \ldots \qquad \ldots \qquad \ldots \quad (III)$$

## ACKNOWLEDGEMENT

*Note.*--Substances whose vapour pressures have been determined by the effusion method, so far as they are known to me, are the following :

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$\left.\begin{array}{l} \text{Ag—Harteck} \\ \text{Au – Harteck} \end{array}\right\}$ *Loc. Cit.*

$\left.\begin{array}{l} \text{Zn} \\ \text{Cd} \end{array}\right\}$ —Egerton, *Phil Mag.* **33,** 33, 1917.

Hg—Knudsen *Ann der Physik* **29,** 179, 1909.

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Ca—Harteck *Loc. Cit.*

Sn—Harteck *Loc. Cit.*

Pb—Egerton, *Proc. Roy. Soc.* A **103,** 469, 1923.

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[1] Born and Franck, *Zeits f. Physik* **31**, 411, 1925.

[2] Dutta and Saha, *Bul. Acad. Sci. U. P.* 1, 19, 1931.

[3] Knudsen, *Ann der Physik* **29**, 179, 1909.

[4] Landolt and Börnstein tables, *3rd Ed.*, *Berlin*, 1923, p. 1029.

# AN X-RAY INVESTIGATION OF THE CRYSTALS OF DIPHENYL NITROSOAMINE.

By Mata Prasad and S. G. Khubchandani

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Diphenyl nitrosoamine was crystallised from a mixture of alcohol and benzene. The crystals have been examined crystallographically and have been found to develop c (001) and m (110) faces. q (011) and o (10$\bar{1}$) also appear but not in a well developed form. The crystals belong to the monoclinic prismatic class and the axial ratio is[1]

$$a : b : c = 0\cdot9635 : 1 : 1\cdot5637$$
$$\beta = 90° \ 58'$$

The crystals were examined by the rotating crystal method. The rotation photographs were taken by means of Shearer X-ray tube fitted with copper anticathode: those obtained about a and b axes are shown in figures 1 and 2 (plate I). The lengths of the axes were determined from

$$l = \frac{n\lambda}{2z}\sqrt{(2r)^2 + (2D)^2}$$

where  $l$ = the length of the axis,

$n$ = the order of the hyperbola,

$\lambda$ = the wavelength of the incident X-rays,

$z$ = the distance of a spot from the zero line,

$r$ = the distance of the spot from the centre,

D = the distance of the plate from the crystal.

The mean values of a, b and c were thus found to be

$$a = 17\cdot08 \text{ Å}; \quad b = 8\cdot8675 \text{ Å}; \quad c = 28\cdot07 \text{ Å}.$$

The axial ratio is

$$a \,:\, b \,:\, c \;=\; 1\cdot926 \,:\, 1 \,:\, 3\cdot166$$

The value of $\beta$ was assumed to be 90° 58', the same as the value given by Groth. It can be seen from the above that the ratios of a & b and of c & b are exactly twice of that found by the crystallographic measurements.

Oscillation photographs about the a and b axes were taken at an interval of 15° and the indices of the reflecting planes corresponding to the spots on the oscillation photographs were worked out by Bernal's method of analysis.[2]

The planes observed, together with an approximate idea of their relative intensities, are given in tables 1 and 2. The method adopted in estimating the intensity of the spot was that used by Robertson.[3] The symbols used have the following meaning:

| v. s. = very strong | m = medium |
|---|---|
| s. = strong | w. m. = weak medium |
| m. s. = medium strong | w = weak |
| v. w. = very weak. | |

*Table 1*

| Axial Planes | | (h0l) Planes | | (h0$\bar{l}$) Planes | | (0kl) Planes | | (hk0) Planes | |
|---|---|---|---|---|---|---|---|---|---|
| 004 | v. s. | 202 | m. s. | 20$\bar{2}$ | m. s. | 012 | s. | 210 | v. s. |
| 008 | s. | 206 | v. s. | 20$\bar{6}$ | v. s. | 016 | v. s. | 230 | s. |
| 0012 | v. w. | 2010 | m. | 201$\bar{0}$ | m. | 0110 | m. | 420 | m. |
| 020 | v. s. | 2014 | m. s. | 201$\bar{4}$ | m. | 0114 | w. m. | 610 | w. m. |
| 400 | v. s. | 404 | s. | 40$\bar{4}$ | s. | 024 | s. | 620 | v. w. |
| 600 | w. | 406 | v. w. | ... | | 028 | s. | 820 | w. |
| 800 | w. | 408 | w. m. | ... | | 0212 | w. m. | | |
| | | ... | | 60$\bar{2}$ | m. | 0214 | m. s. | | |
| | | ... | | 60$\bar{4}$ | m. | 032 | s. | | |
| | | 606 | s. | 60$\bar{6}$ | w. | 036 | m. s. | | |
| | | 6010 | m. s. | 601$\bar{0}$ | w. m. | 0310 | m. s. | | |
| | | 802 | w. | ... | | 048 | m. | | |
| | | 804 | w. m. | 80$\bar{4}$ | w. | | | | |
| | | ... | | 80$\bar{6}$ | w. | | | | |

*Table 2.— General Planes.*

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 111 | s. | 11$\bar1$ | s. | 214 | s. | 21$\bar4$ | s. | 311 | w. | 31$\bar1$ | m. |
| 113 | s. | ... | | 218 | m. | 21$\bar8$ | m. | 313 | v. s. | 31$\bar3$ | v. s. |
| 115 | v. s. | 11$\bar5$ | v. s. | ... | | 21$\overline{10}$ | m. s. | 315 | v. s. | 31$\bar5$ | s. |
| 119 | m. s. | 11$\bar9$ | m. s. | 2112 | w. | 21$\overline{12}$ | v. w. | 317 | m. s. | ... | |
| 1113 | w. | 111$\bar3$ | v. w. | 222 | s. | 22$\bar2$ | s. | 319 | m. s. | 31$\bar9$ | v. w. |
| 1115 | w. | 111$\bar5$ | v. w. | 226 | s. | 22$\bar6$ | s. | 3111 | w. m. | 31$\overline{11}$ | v. w. |
| 121 | v. s. | $\bar1$21 | v. s. | ... | | 22$\bar8$ | m. s. | 3113 | m. | ... | |
| 125 | s. | 12$\bar5$ | v. s. | 2210 | m. s. | 22$\overline{10}$ | m. s. | 321 | v. s. | ... | |
| 127 | m. s. | ... | | 2214 | w. m. | ... | | ... | | 32$\bar3$ | v. w. |
| 129 | m. s. | 12$\bar9$ | m. s. | 232 | m. s. | 23$\bar2$ | w. m. | 325 | m. s. | 32$\bar5$ | s. |
| 131 | s. | ... | | 234 | m. | 23$\bar4$ | m. s. | 327 | w. m. | 32$\bar7$ | w. m. |
| 133 | v. w. | 13$\bar3$ | w. m. | ... | | 23$\bar6$ | v. w. | 3213 | m. | ... | |
| 135 | m. | 13$\bar5$ | m. | 238 | w. m. | 23$\bar8$ | w. m. | 331 | m. | 33$\bar1$ | m. |
| . . | | 13$\bar7$ | m. | ... | | 23$\overline{10}$ | m. | 333 | w. | 33$\bar3$ | v. w. |
| 139 | m. | 13$\bar9$ | w. m. | 242 | w. m. | ... | | 337 | m. s. | 33$\bar7$ | m. s. |
| 141 | w. m. | ... | | ... | | 24$\bar4$ | w. m. | ... | | 34$\bar3$ | w. |
| 143 | w. m. | ... | | 246 | w. m. | 24$\bar6$ | m. | 345 | w. m. | 34$\bar5$ | m. |
| 145 | m. s. | 14$\bar5$ | m. s. | | | | | | | | |
| 147 | w. | 14$\bar7$ | m. | | | | | | | | |
| 412 | m. s. | 41$\bar2$ | s. | 511 | m. s. | 51$\bar1$ | s. | 612 | m. s. | 61$\bar2$ | v. w. |
| 416 | w. | 41$\bar6$ | w. m. | 513 | v. s. | 51$\bar3$ | v. s. | 614 | w. m. | 61$\bar4$ | w. |
| 418 | v. w. | 418 | | 515 | w. | 51$\bar5$ | w. | ... | | 61$\bar6$ | m. s. |

### Table 2 (continued)

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 4110 | m. s. | ... | | 517 | s. | $51\bar{7}$ | m. | 618 | m. s. | 618 | m. s. |
| ... | | $411\bar{4}$ | w. | 519 | m. | $51\bar{9}$ | v. w. | 6112 | m. s. | ... | |
| 424 | m. | $42\bar{4}$ | w. m. | 521 | s. | $52\bar{1}$ | s. | 622 | w. m. | $62\bar{2}$ | m. s. |
| 428 | v. w. | $42\bar{8}$ | m. s. | ... | | $52\bar{3}$ | m. s. | 626 | w. m. | $62\bar{6}$ | m. |
| 4212 | w. m. | $421\bar{2}$ | v. w. | 525 | m. s. | $52\bar{5}$ | m. s. | 628 | w. m. | $62\bar{8}$ | m. |
| 432 | w. m. | ... | | 527 | m. | $52\bar{7}$ | m. | 6210 | w. | $621\bar{0}$ | v. w. |
| ... | | $43\bar{4}$ | m. s. | ... | | $52\bar{9}$ | v. w. | 632 | v. w. | $63\bar{2}$ | m. |
| ... | | $43\bar{6}$ | m. | 5211 | w. | $521\bar{1}$ | v. w. | $63\bar{4}$ | v. w. | $63\bar{4}$ | v. w. |
| 438 | m. s. | ... | | 5213 | v. w. | ... | | 638 | w. | ... | |
| 4310 | v. w. | $431\bar{0}$ | v. m. | 535 | w. | $53\bar{5}$ | w. | ... | | $631\bar{0}$ | w. |
| 444 | m. | $44\bar{4}$ | w. m. | ... | | $53\bar{3}$ | w. m. | ... | | $64\bar{2}$ | v. w. |
| ... | | $44\bar{8}$ | w. | 537 | m. s. | $53\bar{7}$ | m. s. | .. | | $64\bar{6}$ | m. |
| | | | | 539 | w. m. | $53\bar{9}$ | w. | | | | |
| | | | | 5311 | w. | $531\bar{1}$ | v. w. | | | | |
| | | 711 | w. m. | ... | | 812 | m. s. | ... | | | |
| | | 713 | m. s. | $71\bar{3}$ | m. | 816 | w. | .. | | | |
| | | 715 | w. | ... | | ... | | $82\bar{4}$ | w. m. | | |
| | | 717 | w. | $71\bar{7}$ | w. | | | | | | |
| | | ... | | $71\bar{9}$ | w. | | | | | | |
| | | 723 | v. w. | $72\bar{3}$ | m. | | | | | | |
| | | 725 | m. s. | $72\bar{5}$ | w. | | | | | | |
| | | 731 | m. s. | ... | | | | | | | |
| | | 733 | v. w. | ... | | | | | | | |

It will be seen from the above list that the planes (001) are quartered and (100) and (010) are halved and (hkl) planes are halved when (h+l) is odd. These halvings correspond to the space group $C_{2h}^3$ with $\overline{m}$ Bravais Lattice.[4]

The number of molecules in the unit cell required by the space group $C_{2h}$ is sixteen. The number of molecules in the unit cell calculated from the dimensions of the cell and the specific gravity of the crystals which was found to be 1·251, also comes out to be nearly sixteen. This indicates that the molecules of diphenyl nitrosoamine in the cell are asymmetric.

The chemical structure of diphenyl nitrosoamine is represented as
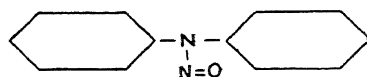


If the benzene rings are assumed to be plane rings of carbon atoms having diameter 1·42 Å and the centres of the carbon atoms and that of the nitrogen atom lie on the same line, the length of the molecule comes out to be nearly 12 Å.

It will be seen from the list of the planes that (hkl) and (hk$\bar{l}$) have in the majority of cases nearly the same intensity. The unit cell, therefore, behaves like an orthogonal cell: this, however, is expected as the angle $\beta$ is nearly 90°.

From the quartering of the (001) planes it appears that the molecules of diphenyl nitrosoamine in the unit cell lie with their length parallel to the $c$ axis. But as the length provided for the purpose is only about 7 Å, it appears that the molecules in the cell are situated not in the manner indicated above but probably as
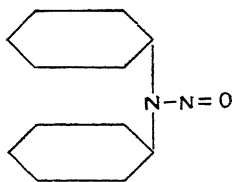


The considerations of the dimensions of this arrangement of the rings and those of the unit cell further indicate that the two rings are situated nearer to the ac face than to the bc face and they are slightly inclined to each other and to the ac face. The oxygen atom is probably situated along the direction of the b axis. This arrangement of two rings is different from the one which has been observed

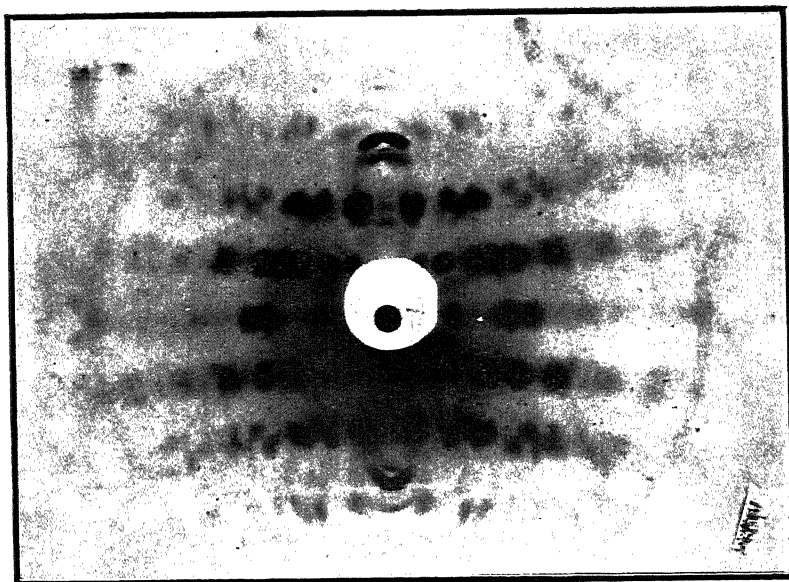in the unit cells of diphenyl or other substances of similar structure studied in this laboratory.

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[1]　Groth, *Chemische Krystallographie*, 5, 50.

[2]　*Proc. Roc. Soc.* A. 123, 113, 1926.

[3]　Robertson, *Proc. Roy. Soc.* A. 118, 712, 1928.

[4]　Astbury and Yardly, *Phil. Trans.* A 224, 221-257, 1924.
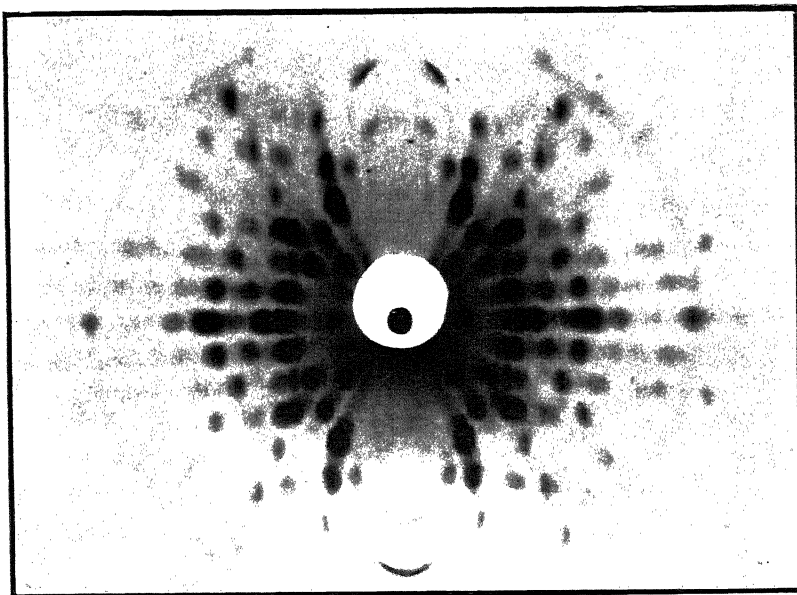
Rotation Photograph about the *a*-axis



Rotation Photograph about the *b*-axis

# VISCOSITY OF FERRIC PHOSPHATE SOL AT VARIOUS PRESSURES

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In several publications Dhar and coworkers[1] have shown that the viscosity of sols goes on increasing with dialysis and finally the sol becomes very viscous and has a tendency to set to a jelly. We have shown[2] in the case of such sols as those of gelatine, agar, etc., that there exists a definite labile structure of the colloid particles, which can suitably explain their high viscosity.

Moreover, in recent years a large amount of work is accumulating on the measurement of viscosity of colloids and it has been found that there exists a great anomaly in this physical property of colloids. Thus Hess[3] showed with blood sols, Hatschek[4] with gelatine sols, Herschel and Bulkley[5] with rubber sols. Ostwald and coworkers[6] with gelatine and mercury sulphosalicylate sols that the viscosity coefficients differed with the change in the shearing force causing the flow of the sols. In fact they observed that the so-called viscosity remarkably decreases as the force of shear is increased. Similarly, Freundlich and coworkers[7] have shown with some inorganic colloids like those of ferric hydroxide (aged) and vanadium pentoxide, that the simple law of Poisenille, viz., that the rate of flow is directly proportional to the shearing force, is not applicable in such cases. In view of these facts we have studied the viscosity of ferric phosphate sol of various degree of purity at various stages of dialysis under variable pressures. Ferric phosphate sol is well known to form viscous sols and yield gels. The viscosity of the sol at various pressures is measured with the apparatus designed by Hoskings[8] to measuring the viscosity of liquids. In order to control the pressure changes during the flow. An empty vessel of 8 to 10 litres capacity was introduced between the manometer and the apparatus.

Ferric phosphate sol was prepared by adding $KH_2PO_4$ solution to a fairly concentrated $FeCl_3$ solution in small amounts at the room temperature till the sol formed assumes a pale yellow colour. The sol of ferric phosphate thus obtained contains an excess of $FeCl_3$, and HCl and KCl obtained by the reaction. The sol was kept in a parchment paper for dialysis and as the dialysis progressed the sol was gradually freed from the impurities and thus we obtained the sols of ferric phosphate of various degrees of purity. The purity of the sol was determined from

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the estimation of chloride ions present in the sol. The viscosity measurements were carried on at 22°C.

### Table 1.

Sol dialysed for 4 days.

Strength of the sol=21˙36 grams of ferric phosphate per litre (Sol A).

(Sol A)

| Pressure Cms. water column. | S (sol)/$\eta_\omega$ |
|---|---|
| 19˙8 | 1˙146 |
| 30˙0 | 1˙098 |
| 40˙0 | 1˙093 |
| 50˙2 | 1˙089 |
| 60˙0 | 1˙085 |
| 70˙5 | 1˙083 |

### Table 2.

Sol dialysed for 6 days.

Strength of the sol = 20˙82 grms. ferric phosphate per litre (Sol A).

| Pressure Cms. water column. | Sol A S (sol)/$\eta$ | Sol A/2 S (sol)/$\eta_\omega$ | Sol A/4 S (sol)/$\eta_\omega$ |
|---|---|---|---|
| 19˙8 | 1˙368 | 1˙136 | 1˙070 |
| 30˙0 | 1˙277 | 1˙095 | 1˙048 |
| 40˙0 | 1˙237 | 1˙092 | 1˙046 |
| 50˙2 | 1˙224 | 1˙089 | 1˙042 |
| 60˙0 | 1˙218 | 1˙085 | 1˙040 |
| 70˙5 | 1˙213 | 1˙083 | 1˙040 |

### Table 3.

Sol dialysed for 8 days.

Strength of the sol=19˙64 grms. ferric phosphate per litre (Sol A).

| Pressure Cms. water column | Sol A S (sol)/$\eta_\omega$ | Sol A/2 S (sol)/$\eta_\omega$ | Sol A/4 S (sol)/$\eta_\omega$ |
|---|---|---|---|
| 19˙8 | 1˙545 | 1˙282 | 1˙155 |
| 30˙0 | 1˙513 | 1˙272 | 1˙138 |
| 40˙0 | 1˙500 | 1˙265 | 1˙135 |
| 50˙2 | 1˙494 | 1˙260 | 1˙131 |
| 60˙0 | 1˙488 | 1˙258 | 1˙127 |
| 70˙5 | 1˙485 | 1˙256 | 1˙127 |

*Table 4.*

Sol dialysed for 10 days.

Strength of the sol = 19·0 grms. ferric phosphate per litre (Sol A).

| Pressure Cms. water column | Sol A $S(sol)/\eta_\omega$ | Sol A/2 $S(sol)/\eta_\omega$ | Sol A/4 $S(sol)/\eta_\omega$ |
|---|---|---|---|
| 19·8 | 3·545 | 1·997 | 1·395 |
| 30·0 | 3·489 | 1·908 | 1·362 |
| 40·0 | 3·415 | 1·890 | 1·346 |
| 50·2 | 3·373 | 1·876 | 1·325 |
| 60·0 | 3·333 | 1·865 | 1·304 |
| 70·5 | 3·250 | 1·855 | 1·300 |

From our experimental results we find that with the progress of dialysis the sol becomes unstable and the viscosity $s$ increases rapidly with purity, *e.g.*, as the impurities possessing the stabilising effect on the sol are removed the sol becomes unstable and viscous. Similar results have been obtained by Dhar and coworkers with other sols. Our results, however, show that the increase in the viscosity $s$ of ferric phosphate sol of various grades of purity is less marked when the flow is caused by high pressures. Similarly, in the case of diluted sols, the increase in the value of $s$ with the progress of dialysis is not so marked as in the case of concentrated ones.

We are, therefore, of opinion that a high rise in the viscosity of sols as is generally observed during the process of dialysis and measured by an Ostwald's viscometer is certainly due to the fact that the pressure causing the flow of a colloid in an Ostwald's viscometer is very low. It appears to us that if the measurements of the rates of flow of a colloid be undertaken at fairly high pressures (this may not be experimentally possible because of turbulent flow) the change in the viscosity of colloids when it is purified be either nil or insignificant.

It is also seen from our results that the value of $s$ increases more rapidly with the increasing concentration of the dispersing medium than that demanded by any linear relationship and a sol of ferric phosphate behaves like some typical hydrophilic colloids as those of gelatine, agar, starch, etc. It may be mentioned here that simple equation connecting the concentration of a colloid with its viscosity was first given by Einstein,[9] *viz.*, $\eta_s = \eta_\omega(1 + a\,\phi)$, where $\eta_s$ and $\eta_\omega$ represent the viscosities of the sol and water respectively, $a$ is a constant and $\phi$ is the ratio of the total volume of the dispersed phase to the volume of the sol. From time to time this equation has been put to experimental test and has been found to be not applicable specially in the case of lyophilic colloids. Several other relations have been proposed by Hess,[10] Hatschek,[11] Arrhenius[12] and others to correlate the viscosity of a sol with the concentration of the dispersed phase. Our experimental results show that as the pressure causing the flow of a sol of ferric phosphate

increases the curves connecting viscosity with the concentration of ferric phosphate gradually flatten out to assume the form of a straight line. We think, therefore, that in view of the fact that there is a wide variation of viscosity and that of a tendency for the change in the nature of the concentration viscosity curves with the rate of shear, it is not profitable to use the formula of Hess, Hatschek, Arrhenius and others and to calculate the degree of hydration therefrom.

It is generally believed by colloid chemists that a high viscosity of sol is due to a high hydration of colloid particles. According to this view we have to explain our experimental results on the assumption that the hydration of the colloid particles is changeable by the shearing force, which causes the flow of the sol through a capillary; moreover, we have to assume that the hydration of the colloid particles increase with dimunition in their electrical charge.

From our results it is seen that the percentage increase of viscosity at lower rates of shear is highly magnified with the greater purity of sols. In some cases a pure sol has a viscosity 2'5 to 3 times that of a sol which is comparatively impure. This will lead us to assume that a large increment in hydration occurs as the electric charge on the colloid particle is diminished. This increased hydration will then cause the effective volume of the colloid particle to become very large and we are to assume that the adsorption of water by a colloid particle is several molecules deep. From our knowledge of Langmuir's theory[13] of adsorption it seems improbable. Again, it is seen from our results that in general even a pressure so low as 40 cm. water column causes the viscosity value $s$ to decrease appreciably. This has to be explained as due to decreased hydration by this pressure, $i.e.$, even a small shear will tear off some water molecules wrapping the colloid particle. In other words, the hydration will have to be assumed to be very labile and decreasing with increasing shearing force and hence causing the decrease in the viscosity values.

In diluted sols it is expected that a colloid particle is hydrated to a greater extent than in concentrated ones and as a consequence one expects the increase in the value of $s$ with progress of dialysis and the fall in the value of $s$ with increasing shearing force to be more pronounced and rapid with diluted sols than with concentrated ones. Our experimental results, on the other hand, show that in the case of diluted sols the increase in the value of $s$ with the progress of dialysis and the decrease in the value of $s$ with increasing shearing force is not so marked as in the case of the concentrated sols.

In our opinion the sols which are specially viscous and yield gels have a distinct orientation of particles even when present in the liquid condition. Certainly, this orientation increases as the electric charge on the colloid particles is decreased. Continued dialysis gradually lowers the electric charge on the colloid particles, which we have measured by the coagulation experiments and hence we find that the value of $s$ remarkably increases as the sol is purified by the process of continued dialysis. At high pressures, this orientation of colloid particles is

destroyed to a greater degree than at low pressures and hence the percentage increase of $s$ is less with high pressures than with lower ones as the sol is dialysed. In the case of the diluted sols, this orientation is not so marked because of smaller concentrations of the colloid aggregates and, therefore, the effect of varying shearing force is not so pronounced in this case as with concentrated sols.

It has been suggested by us about two years ago[2] that the force which causes this arrangement or orientation of particles originates from a 'loose crystallographic force'. In our experiments with soaps, gelatine and agar we have shown that all these highly viscous lyophilic colloids posses an orientation of the colloid particles and either stirring these sols or sowing them with an already formed gel of the same concentration facilitates this orientation to a great extent and we get increased viscosity. This is similar to a release of supersaturation from a supersaturated solution of dissolved substances by the crystallographic forces. Our results of sowing the sol of ferric phosphate with an already formed gel are given below :—

*Table 5.*

Effect of sowing with formed gel.   Temperature $= 22°$C.

| Pressure Cms. water column | $S \text{ (sol)}/\eta_\omega$ ordinarily | $S \text{ (sol)}/\eta_\omega$ after sowing with already formed gel of FePo$_4$ |
|---|---|---|
| 40 | 10·481 | 10·962 |
| 50 | 10·121 | 10·601 |
| 60 | 9·942 | 10·392 |
| 70 | 9·667 | 10·108 |

It may be mentioned here that the concentration, electrical conductivity and the stability of ferric phosphate sol were not changed by sowing.

The rigidity in the case of lyophilic colloids has been found to exist in measurable amounts by several investigatiors.[1a] We are of opinion that this distinct rigidity observed with highly viscous sols is due to a certain orientation of the colloid particles originating from the forces which are inherent on the solid surface to form bigger aggregates. High hydration of colloid particles, however, checks the actual aggregation. The force, which causes this orientation of colloid particles of the sol is also of the smaller magnitude and hence the rigidity is not high and the sol for a particular shearing force behaves as a liquid.

We are, therefore, of opinion that the lyophilic colloids like gelatine, agar, silicic acid, ferric phosphate, etc., show a high viscosity due to an orientation of the colloid particles rather than due to the high hydration of the dispersed phase.

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Each of these sols should show a curvilinear viscosity/concentration relation and should also show a remarkable difference in the so-called viscosity with different rates of shear, *i.e.*, will show the property of plastic flow.

It is needless to mention that the simple conception of the viscous flow as advanced by Maxwell for gases does not remain simple in the case of liquids and in its turn becomes more complex in the case of the sols. It appears to us that the so-called viscosity *s* cannot be regarded as the true viscosity of the sol and may be termed as the coefficient of structural flow for a definite rate of shear.

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# INFLUENCE OF TEMPERATURE AND LIGHT INTENSITY ON PHOTOSYNTHESIS AND RESPIRATION AND AN EXPLANATION OF "SOLARISATION" AND "COMPENSATION POINT."

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## ABSTRACT

1. The Arrhenius relation connecting velocity and temperature of a reaction which is applicable to ordinary chemical reactions, is not valid in the case of the influence of temperature on photosynthesis and respiration in plants. The non-applicability of the Arrhenius relation to photosynthesis and many other phenomena in plant life can be explained from the following considerations—

(a) It appears that in plant life, the following opposing reactions are taking place :
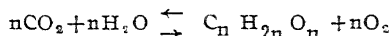
$$nCO_2 + nH_2O \underset{\rightarrow}{\leftarrow} C_n H_{2n} O_n + nO_2$$

The direct action (photosynthesis) is being opposed by the reverse reaction (respiration) which increases according to the law of mass action with increase in the concentration of carbohydrates formed from photosynthesis.

(b) There is reason to believe that the velocity of respiration in plants is appreciably accelerated by light.

(c) The influence of temperature on respiration appears to be greater than that on photosynthesis.

2. The greater influence of temperature on photosynthesis in presence of strong light than that in weak light can be explained from the foregoing considerations. Hence, it is needless to assume that there are two reactions involved in photo-synthesis.

3. The observations of Willstätter and Stoll that leaves of low chlorophyll content show a lower acceleration of photosynthesis with increase in temperature than the leaves of high chlorophyll content have also been explained from the same point of view.

4. The experiments of Willstätter and Stoll showing that in chlorophyll rich leaves an increase of light intensity does not affect photosynthesis have been explained from the view point of " exhaustion effect " as observed in ordinary photochemical reactions.

5. That oxygen is essential for photosynthesis appears to be due to the fact that plant life depends on oxygen respiration and the activity of the plant and along with it its photosynthetic power depend on its respiratory activity.

6. The photosynthetic activity is exceedingly high in young leaves and is not proportional to the chlorophyll content. This is because that the respiratory activity of young leaves is very high. In plant life, as well as in animal life, metabolism decreases with age.

7. In plant life in the absence of iron compounds, respiration and photosynthesis become defective as in chlorotic plants, because iron compounds accelerate respiration.

8. It appears that the factor which really controls plant life is its respiratory or metabolic activity.

9. In the animal world, the length of life depends inversely as the rate of living The duration of the catalytic activity of an active catalyst appears to be short. These considerations

are applicable to plant life as well. In leaves, poor in chlorophyll, the time factor appears more slowly than in chlorophyll rich leaves. In other words, the activity of chlorophyll rich leaves would last for a shorter period than that of chlorophyll poor leaves.

10. The phenomenon of "solarisation", that is, the disappearance of carbohydrates formed from photosynthesis after prolonged illumination appears to be due to respiration, that is, their oxidation by oxygen in presence of light. The respiration, that is, the oxidation of carbohydrates is also increased by increase of temperature caused by light absorption.

11. The compensation point, that is, the light intensity at which the photosynthetic and respiratory activities of plants compensate each other, decreases with decrease of temperature. A certain light intensity which at 20° represents the compensation point, causes an evolution of oxygen due to photosynthesis at 5°. In nature, under certain conditions and at high temperature, the plant cannot store any material due to photosynthesis on account of high respiratory activity, whilst at low temperatures, with the same light intensity, food materials are formed by photosynthesis. The above results have been explained from the following considerations:

(i) Photosynthesis is proportional to the light intensity, there being no photosynthesis in dark.

(ii) Respiration takes place in the dark but is appreciably accelerated by light.

(iii) An increase in temperature affects more markedly respiration than photosynthesis.

12. Respiration appears to be the more fundamental reaction in plant and is more important to plant life than photosynthesis which predominates in plants only under restricted conditions of temperature and light intensity.

## INFLUENCE OF TEMPERATURE ON RESPIRATION

The influence of temperature on respiration has been investigated with plants and animals. Generally an increase of temperature leads to an increase in the respiration of plants and animals.

Miss Matthaei (1904) determined the carbon dioxide evolution of 2 grams of cherry laurel leaf per hour at various temperatures From the experiments of Miss Matthaei a smooth curve has been plotted and the following results are obtained from the curve : —

| Temperature. | $CO_2$ evolution in gm. | Temperature coefficient for a 10° rise of temperature observed. | Temperature coefficient for a 10° rise calculated from Arrhenius equation. |
|---|---|---|---|
| 5°<br>15° | 0 000085<br>0·00032 | 3·76 | 3·76 |
| 10°<br>20° | 0·000175<br>0·000485 | 2·77 | 3·55 |
| 15°<br>25° | 0·00032<br>0·000585 | 1·83 | 3·44 |
| 20°<br>30° | 0 000485<br>0·00094 | 1·94 | 3 30 |

When the temperature is higher than 30°, marked variation in the amount of respiration is observed and Miss Matthaei obtained the following results with 2 grams of cherry laurel leaf

| Temperature. | $CO_2$ evolution in gm. |
|---|---|
| 38°·3 | 0·00205 |
| 38°·3 | 0·00230 |
| 40°·9 | 0·0014 |
| 40°·9 | 0·0016 |
| 42°·9 | 0·0015 |
| 42°·9 | 0·0014 |

More or less similar variations are observed with photosynthesis at higher temperatures.

The experiments of Kuijper (1910) on the respiration of active seedlings of the lupin, pea and wheat at various temperatures are in general agreement with those of Miss Matthaei. The following results have been obtained from a smooth curve plotted with the values on respiration recorded by Kuijper with pea at different temperatures :—

| Temperature. | $CO_2$ evolved in milligrams. | Temperature coefficient for a 10° degree rise of temperature. | Temperature coefficient for a 10° rise calculated from Arrhenius equation. |
|---|---|---|---|
| 0° 10° | 3·5 11·5 | 3·27 | 3·27 |
| 5° 15° | 6·5 17·5 | 2·7 | 3·14 |
| 10° 20° | 11·5 27·5 | 2·4 | 3·02 |
| 15° 25° | 17·5 46·5 | 2·6 | 2·91 |
| 20° 30° | 27·5 58·0 | 2·1 | 2·80 |

The experiments of Kuijper show that there is fluctuation in the amount of carbon dioxide evolution at temperatures higher than 30°. At temperatures higher than 35°, there is a steady reduction in the amount of carbon dioxide given out with time. Hée ( Thèse, Paris 1930 ) also obtained high values of temperature coefficients of respiration with some plants.

Müller-Thurgau and Schneider-Orelli (1910) obtained some peculiar results on the influence of temperature on the respiration of potato tubers. They reported that when the tubers are heated to 40° for some hours, the respiration activity

increases even when the tubers are brought to room temperature and a permanent increase in respiratory activity is observed when the tuber is heated to 44°. These results are different from those obtained by Miss Matthaei and Kuijper who believed that there are two different processes involved in plant respiration, one of which is accelerated and the other retarded by increase of temperature. Müller-Thurgau and Kuijper realised that the influence of temperature on respiration will vary with the nature of the available material undergoing oxidation in the plant. It will be of interest to note that de Boer (1928) reported that in *Phycomyces*, the normal oxidation of fats takes place at low temperatures, whilst at high temperatures carbohydrates are more easily assimilated.

Lundegardh (1924) advanced the view that the temperature-respiration curves can be divided into four sections. In the first section, which goes up to 40°, the curve shows a steady increase of respiration with increase of temperature and in this region the temperature coefficient of respiration for a 10° rise of temperature varies from 1·9 to 3·3. From 40° to 46°, a rapid rise of respiration is observed. In the third section from 46° to 50°, a rise is obtained with an optimum at 50°, above which there is a rapid fall of respiration.

Several plant physiologists believe that the respiration of higher plants increases with increase of temperature according to the van't Hoff rule. Thus Kuijper, Harder (1915) working at temperatures 5° and 25° and Plaetzer (1917) with *Clado phora* obtained the value 2 for the temperature coefficient of respiration for a 10° rise of temperature and Noak (1920) reported the value 1·8 in the respiration of thermo philous fungi. It is well-known that the Arrhenius relation $\log_e \dfrac{k_1}{k_2} = \dfrac{A\,(T_1 - T_2)}{T_1\,T_2}$ is applicable to chemical reactions (where $K_1$ and $K_2$ are the velocities of the reaction at $T_1$ and $T_2$ absolute temperatures and A is a constant) and the application of this relation to physiological processes is certainly more correct than to apply the van't Hoff rule, that the temperature coefficient of a chemical reaction varies from 2 to 3 because there are several chemical changes of which the temperature coefficients are much greater than 3 and in many cases, the temperature coefficient may be as high as 7 for a 10° rise of temperature. From the tables recorded above, it will be observed that the Arrhenius relation which is applicable to chemical reactions, does not apply to the problem of plant respiration. The values calculated according to the Arrhenius equation are always greater than those observed.

Recently Crozier (1924-25) has attempted to apply the equation of Arrhenius as modified by Marcelin and Rice to the results on respiration at different temperatures. The Arrhenius constant A has been designated by Crozier as "temperature characteristic" and he believes that there are three values of "temperature characteristic" for respiration.

It has been reported that with succulents at low temperatures, incomplete oxidation of sugar takes place and organic acids are generated and the respiratory quotient $CO_2/O_2$ is less than unity. When the temperature is increased, sugar is com-

pletely burnt to carbon dioxide and water and the respiratory quotient becomes unity.

It is well known that photosynthesis can go on at low temperatures, respiration also continues with seeds lichens and mosses at low temperatures even up to —25°.

From the foregoing results on the influence of temperature on plant respiration, a very important conclusion can be drawn which is this :—That the influence of temperature on respiration is greater than that on photosynthesis. The results of Miss Matthaei on photosynthesis show that the temperature coefficients of photosynthesis between 0° and 10° and 10° and 20° are 2·71 and 2·21 respectively, whilst her results on respiration are 3·76 between 5° and 15° and 2·77 between 10° and 20°. The respiration temperature coefficients of Kuijper give the value 3·27 between 0° and 10°. Similar results have been obtained by Hée and other workers. This important relation that in general, temperature affects respiration more markedly than photosynthesis in plants plays an important rôle in the economy of nature. This difference in temperature effect considerably affects the equilibrium in the amount of photosynthesis and respiration in plants. In a subsequent section the importance of this relation in explaining many plant processes will be discussed.

In cold-blooded animals, which are somewhat allied to plants the respiratory exchange always increases with increasing temperature. With several varieties of flies *Cyclodes gigas*, fishes, etc., marked influence of temperature on respiration has been reported.

## INFLUENCE OF LIGHT ON RESPIRATION

Although several authors notably Moleschott, Selmi and Pott observed that the expiratory exchange of animals (*e.g.*, dog, mouse, frogs, etc.) is higher in light than in darkness, the experiments of Loeb on chrysalides of butterflies and Ewald on curarized frogs do not warrant the same conclusion.

The investigation on the influence of light on the respiration of green plants becomes complicated because on illumination, the carbon dioxide and water produced in respiration undergo photosynthesis to reform the carbohydrates and other food materials. Borodin (1876) showed that leafy shoots undergo respiration more vigorously after an exposure to light. Miss Matthaei observed that the respiration of a leaf in the dark falls off continuously, whilst on illumination lasting for four or five hours the respiratory values may be doubled and that the increase in respiration is not concomitant with the amount of carbon dioxide assimilated. Moreover Rose (1910) reported a high intensity of respiration in green plants in bright sunshine. Recently Shri Ranjan (1932) has observed increased respiration on illumination with croton, free from chlorophyll. Spoehr (1915) has reported that during the day, the respiration of plants is increased. Moreover, Middleton (1927) with barley seedlings and Whimster with *Pelargonium zonale*, have reported

a marked increase of respiration in air ionised by the radioactive element polonium.

From the foregoing observations the author has come to the conclusion that although in presence of light, the materials available for respiration increase due to photosynthesis and this leads to an increase in respiration, the chemical changes involved in the oxidation of food materials are also accelerated by the absorption of light. Moreover Dhar and collaborators have shown that the food materials like starch, sugars, proteins and fats in aqueous solutions or suspensions are oxidized to carbon dioxide and water by simply passing air at the ordinary temperature in presence of sunlight. In absence of light, there is no oxidation. In presence of inductors like ferrous hydroxide, cerous hydroxide, glutathione, the food materials are oxidized to carbon dioxide and water by air even in absence of light. In presence of sunlight these induced oxidations are greatly increased. It appears, therefore, that the light absorbed by the plants will also accelerate the oxidation of glucose and other food materials present in the plant. Hence in presence of light the respiration in the plant is likely to be increased.

The author is definitely of opinion that light increases plant respiration as much as animal respiration but the influence of light on respiration is less marked than on photosynthesis.

It is well-known that the Arrhenius equation $\log_e k_1/k_2 = A (T_1 - T_2)/T_1 T_2$ is applicable to ordinary chemical reactions taking place in a homogeneous system ($k_1$ and $k_2$ are the coefficients of the velocities of the reaction at $T_1$ and $T_2$ absolute temperatures and A is a constant).

In a publication, Dhar (1920) has shown that the application of the above Arrhenius relation connecting the velocity and temperature of a reaction is certainly more correct than to apply the van't Hoff rule that the temperature coefficient of a chemical reaction for a ten-degree rise of temperature lies between 2 and 3, because the temperature coefficient does not remain constant at different temperature intervals but falls off with increase of temperature. Moreover Dhar (1917) has shown that for some reactions, the temperature coefficient can have the high value 7·2 for a 10° rise.

Many plant physiologists following the lead of Blackman have applied the van't Hoff rule to plant temperature studies. Thus Stiles (Photosynthesis 1925) states. " Many plant and animal processes have been shown to obey the van't Hoff rule, if only approximately and within limits," and " similar curves for the respiration of higher plants have been constructed by Kuijper, who found the van't Hoff rule followed between 0° and 20°." The application of the Arrhenius relation has been found to be general with ordinary chemical reactions. When the same relation is applied to the results actually obtained regarding the influence of temperature on photosynthesis in plants, it fails, as will be evident from the following table obtained from Warburg's results :—

| Light intensity | Observed | Calc. |
|---|---|---|
| | $\dfrac{k_t+10}{k_t}$ | $\dfrac{k_t+10}{k_t}$ |
| 16 | 2·0 | 4·11 between 16° and 25° (taking 4·7 between 5° and 10°) |
| 45 | 2·1 | 4·01 between 10° and 20° (taking 4·3 between 5° and 10°) |
| 45 | 1·6 | 3·66 between 20° and 30° (taking 4·3 between 5·4° and 10°) |

The results have been calculated by applying the Arrhenius relation. It appears that the temperature coefficients of photosynthesis do not obey the Arrhenius relation, which has been found to be universally applicable to ordinary chemical reactions investigated so far and no case of failure has been reported. In photosynthesis the observed values are always smaller than the calculated values. The reasons of the non-applicability of this relation to photosynthesis in plants are:—(1) the greater influence of temperature on the respiration process than that on photosynthesis and (2) the harmful influence of high temperatures on the chloroplast.

It has already been stated that when the temperature of a plant system undergoing photosynthesis is increased the velocity of photosynthesis is increased but to a smaller extent than that of respiration. Consequently, the temperature coefficient of the observed photosynthesis will appear to be smaller than when the reversible reaction was not present. Moreover, the chloroplast in the protoplasmic cell which is likely to be active in the photosynthetic process starts undergoing deterioration when the temperature is greater than 20° and may be partially destroyed when the temperature is still greater. This is evident on comparing the results obtained by Warburg and those calculated from the Arrhenius relation. The observed temperature coefficients between 16° and 25° and between 10° and 20° are nearly half of the calculated values, whilst the observed temperature coefficient between 20° and 30° is much less than half of the calculated value. The pernicious influence of high temperature on physiological and enzyme and bacterial processes is well known. In most cases the optimum temperature in these reactions is round about 20°. Moreover in plant photosynthesis, there is an additional factor namely, the reverse reaction, e.g., respiration which is also simultaneously going on and is counterbalancing the photosynthetic reaction and hence, the influence of temperature on photosynthesis is less pronounced due to these counteracting agencies.

It has already been stated that in the case of some chemical reactions, the temperature coefficient can have the high value 7·2. Hence it is no wonder that the temperature coefficient of photosynthesis at low temperatures (say between 5° and 10°) has the value 4·3. It seems probable that the photosynthetic reaction is not an adsorption process of which the average temperature coefficient is in the

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neighbourhood of 1'2 for a ten-degree rise of temperature, but it is controlled by a truly photochemical change having a moderately high temperature coefficient. In several communications from these laboratories it has been shown that photochemical reactions need not have temperature coefficients approaching unity but can have values as high as 4. From the foregoing considerations, it is clear that it is needless to assume that the photosynthetic process involves two reactions. It is believed that in high light intensity the chemical reaction (" Blackman reaction " as designated by Warburg) is determining the total velocity of the reaction, because for a ten-degree rise of temperature between 15° and 25°, the velocity of the photosynthesis is doubled. On the other hand, in low light intensity, the temperature coefficient instead of being 2 as with intense light, is 1'06 and hence it has been assumed that the chemical reaction is not the controlling factor as in the previous case ; but the photochemical reaction with a low temperature coefficient determines the photosynthetic rate at low intensities of light.

In presence of intense light, the photochemical reaction causing the photosynthesis and having a moderately large temperature coefficient is predominant and the counteracting influence of the respiration process, which is not as much accelerated by light as the photosynthetic reaction, is not prominent. On the other hand, in presence of feeble illumination, the velocity of the photosynthetic reaction is not high, because this reaction takes place only in light and is proportional to the light intensity. In this case, the counter-acting influence of respiration, especially at increased temperatures, becomes prominent and hence the influence of temperature on the observed photosynthetic rate is feeble.

Warburg (1919) has observed that the temperature coefficient of photosynthesis with the unicellular alga Chlorella is much less when the light intensity is feeble than it is strong. Thus $\frac{k_t + 10}{k_t}$ between 16° and 25° with light intensity 16 = 2'0 and $\frac{k_t + 10}{k_t}$ between 15° and 25° with a relative intensity of 1 = 1'06.

These results which appear to have been confirmed by other workers can be explained in the following way :—

It has already been stated that in a plant, the following opposing reactions are taking place :

$$nCO_2 + nH_2O \; \underset{\rightarrow}{\overset{\leftarrow}{\phantom{x}}} \; C_n H_{2n}O_n + nO_2$$
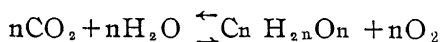
and the temperature coefficient of photosynthesis is less than that of respiration. Hence, when the light intensity is feeble, the velocity of photosynthesis is small and is slightly greater than that of respiration at the same temperature. Now when the temperature of the system is raised through ten degrees, the velocity of the photosynthesis will be increased to a smaller extent than that of respiration. Consequently the temperature coefficient of the observed photosynthesis may be unity or less.

It will be interesting to note in this connection that Harder (1915) working with low light intensity and sea plants of the polar region obtained the following ratio of $\frac{\text{photosynthesis}}{\text{respiration}}$ for different temperatures : —

| | | | |
|---|---|---|---|
| $20° - 22°$ | 0·5882 | 0·4227 | 0·4280 |
| $2° - 3·5°$ | 1·603 | 0·9207 | 2·059 |

Moreover, in nature when the temperature of the air is high, the plants gain no material through photosynthesis because of the high respiration, whilst at lower temperatures with the same light intensity, food materials are formed in the plant

Willstätter and Stoll (1918) have reported that leaves of low chlorophyll content exhibit a lower acceleration with increasing temperature than the leaves of high chlorophyll content. Thus leaves of *Ulmus* with low chlorophyll content showed a temperature coefficient of 1·34 and with high chlorophyll content of 1·53 between 15° and 25°. These results of Willstätter and Stoll can be explained from the view point already advanced.

The important researches of Willstätter and Stoll show that although there are minor discrepancies, the rate of photosynthesis is determined by the chlorophyll content of the plant. Hence in presence of large amounts of chlorophyll in the leaves, the velocity of the photochemical reaction involved in the photosynthetic process will be larger than in the case of leaves containing smaller quantities of chlorophyll. In the case of leaves containing large amounts of chlorophyll, the direct photochemical process being high the reverse reaction of respiration will appear to be less pronounced and this case is comparable to the case previously discussed with high light intensity and hence, temperature increase will lead to an increase of photosynthesis. On the other hand, in presence of small amounts of chlorophyll in the leaves, the photosynthetic rate is low and hence the opposing respiration reaction will appear to be prominent and this case is allied to photosynthesis with low light intensity having a small temperature coefficient.

Willstätter and Stoll obtained the following interesting results : —

Photosynthesis of the green and yellow varieties of Elm 5%$CO_2$ and 24000 Lux.

| Variety Temp. | | Dry weight of leaves | Leaf surface sq. cm. | Chlorophyll mg. | Photosynthesis grm. $CO_2$ hour | |
|---|---|---|---|---|---|---|
| | | | | | 8 grms fresh leaves | 1 sq. m. surface |
| Chlorophyll poor 25° | ... | 2·00 | 321 | 0·95 | 0·075 | 2·3 |
| „ „ 15° | ... | 2·00 | 321 | 0·95 | 0·056 | 1·7 |
| Chlorophyll rich 25° | ... | 2·35 | 421 | 13·0 | 0·089 | 2·1 |
| „ „ 15° | ... | 2·35 | 421 | 13·0 | 0·058 | 1·4 |

The foregoing results show that the temperature coefficient (1·53) of the photosynthesis with chlorophyll rich leaves is greater than that with chlorophyll poor leaves (1·34), although the photosynthesis is not at all proportional to the amount of chlorophyll in the leaves. Willstätter and Stoll find that temperature variations do not affect the rate of photosynthesis of the yellow varieties as much as the normal ones. In the yellow varieties, the amount of photosynthesis being small, the compensating influence of respiration becomes prominent and hence temperature does not appear to influence photosynthesis with these varieties to the same extent as the normal ones with more chlorophyll.

Moreover, differences in light intensity have more profound effect on the yellow varieties than on the normal ones and the time factor appears more slowly than with the normal ones. It is well-known that photosynthesis increases with the light intensity and the chlorophyll content of the leaves. Now in the case of leaves containing much chlorophyll, the velocity of photosynthesis will be high and may reach the maximum, even when the light intensity is not high and hence in these cases, the reaction will be less sensitive to the influence of light changes, because the reaction is already fast due to the presence of large amounts of chlorophyll. On the other hand, when the chlorophyll content is small, the reaction velocity is small and light will affect the velocity more markedly than in the previous case. This explanation is in agreement with the observations of Willstätter and Stoll that in the chlorophyll rich leaves, an increase of light intensity was without influence on photosynthesis; in fact the light intensity could be reduced by 3/8 without affecting the rate of photosynthesis. Exactly similar exhaustion effect has been observed with several photochemical reactions where the velocity of the reaction may be proportional to $I^{\frac{1}{3}}$ or $I^{\frac{1}{4}}$ in some cases where the reaction is very fast.

### RESPIRATION—THE MOST FUNDAMENTAL OF THE PLANT PROCESSES

It seems that in plants as much as in animals, respiration is the most fundamental process, that is going on in the plant system. Photosynthetic activity is a subsidiary reaction, in comparison with respiration. It appears that the various processes which are associated with plant life can only take place as long as respiration lasts.

The activity of a plant is measured by its respiration. It appears that the greater the rate of respiration per unit surface, the greater is the activity of the plant. The amount of respiration would depend on (1) the concentration of carbohydrates and other food materials available in the plant and (2) a minimum oxygen pressure and (3) the activity of the enzymes and inductors When factors (2) and (3) are constant, respiration will depend on the concentration of carbohydrates, proteins and other food materials, which is controlled by the photosynthetic activity of the plant.

The view that respiration is more fundamental in plant life than photosynthesis is supported from the following observations :—

Warburg has reported that, while respiration is not influenced by different partial pressures of oxygen above a certain minimum, photosynthesis is less at

higher pressures.  A change in the partial pressure of oxygen from $\frac{1}{50}$ to 1 atmosphere reduces the photosynthetic rate by about $\frac{1}{3}$.

Wurmser and Jacquot (1923) have observed that when certain marine algae are subjected to temperature from 36° to 45° for 1 to 15 minutes, the rate of photosynthesis is always depressed when the plants are returned to the temperature of the environment (16°).  Similar effects are produced with glycerol.  Warburg has shown that photosynthetic rate is reduced by hydrocyanic acid and urethanes in extreme dilutions in which the respiratory activity is not affected and in certain cases, even stimulated.  It appears, therefore, that photosynthetic process is more sensitive than that of respiration.  As all plant processes depend on respiration, which is the vital reaction in plant life as much as in animal life, photosynthetic activity cannot proceed without respiration taking place in the plant and hence, without the presence of oxygen, which supports respiration in both plant and animal life.  Because lack of oxygen is detrimental to respiration, it is also harmful to photosynthesis.  Consequently, the classical experiments of Boussingault (1868) and Pringsheim (1887) showing that in an atmosphere of hydrogen, nitrogen, carbon dioxide, or methane plants lose the power of photosynthesis, are easily explained from the above view point, because in presence of these gases, oxygen respiration stops.  It appears, therefore, that besides light, chlorophyll, carbon dioxide and moisture supply, respiration is also necessary for photosynthesis.

Willstätter and Stoll have observed that various plants exhibit a wide variation in their resistance to lack of oxygen.  According to Willstätter and Stoll, the the partial pressure of oxygen can be reduced to $1/100^{th}$ of that in air without affecting photosynthesis if the rest of the atmosphere is nitrogen.  After complete displacement of oxygen for two hours, the leaves on illumination cannot effect photosynthesis, although under these conditions, the leaves show no visible signs of injury.  When *Cyclamen europaeum, polytrichum juniperinum* are exposed to oxygen free atmosphere for one hour, the photosynthetic activity is decreased but not entirely stopped.  When the plants are kept in oxygen free atmosphere for 15 to 24 hours, they show no photosynthesis immediately on illumination, but after half an hour or so, photosynthesis begins and continues to a high rate.  Long continued exposure to oxygen free atmosphere produces injurious effect on the photosynthetic mechanism.  The longer the time of exposure of a plant to an atmosphere, free from oxygen, the lower is the rate of subsequent photosynthesis and more incomplete the recovery.  Willstätter and Stoll have concluded from their careful experiments that oxygen is essential for photosynthesis but a small quantity of oxygen is enough for photosynthesis.  Now, as soon as photosynthesis begins, oxygen is generated and respiration goes on.  Lack of oxygen produces a permanent injury to the plant, because respiration which is the most important of the plant processes stops in the absence of oxygen. Moreover, it appears from the foregoing results, that for plants, the oxygen requirement for respiration

is less than in animals and they resist lack of oxygen in their living atmosphere much better than animals.

It has already been stated that the activity of a plant is measured by the amount of its respiration per unit surface. Consequently, the greater the respiration, the greater the activity of the plant and greater the photosynthesis, because photosynthesis, like other plant processes, is associated with the activity of the plant. It has already been stated that in plants, Willstätter and Stoll did not find any direct proportionality between the chlorophyll content and its photosynthetic activity. This is explained from the view-point advanced here that the respiratory activity of the plant is the most vital of the plant processes and all other functions of the plant depend on the respiratory activity and consequently, photosynthetic rate is likely to be more directly proportional to the respiratory activity than to any other single factor, *e.g.*, chlorophyll content, light intensity or carbon dioxide concentration. Experiments are in agreement with this view-point. Plester (1912) showed that the leaves of the light green or yellow varieties have a lower rate of photosynthesis and respiration that the varieties rich in chlorophyll. Although, there is no parallelism between chlorophyll content and photosynthetic rate, the ratio $\frac{respiration}{photosynthesis}$ appears to be constant as will be evident from the following results obtained by Plester with the light green varieties:—

Ptelea=1·77, Catalpa = 1·72, Mirabilis=2·0, Ulmus=2, Populus=2·12. Similar results correlating respiration and photosynthetic rate have been obtained by Miss Henrici (1918) with alpine and low land plants, Boysen-Jensen (1918) and Spoehr and McGee (1923).

Willstätter and Stoll have also studied the photosynthetic activity of leaves of different ages. They have compared the activity of a light green leaf from the end of a branch with that of a dark green leaf from the base of the same branch. Their results are given below:—

*Photosynthesis of leaves from the same plant but in different stages of development at 25° −5% $CO_2$ and 4800 Lux.*

| Species | Date | Description of leaves. | 10 grm. fresh leaves | | Photosynthesis grm. $CO_2$ per hour | | Photo-synthetic number $P_c$ |
|---|---|---|---|---|---|---|---|
| | | | Dry weight grms. | Chlorophyll milligram. | Per 1 grm. dry weight. | Per 1 sq. dm. leaf area. | |
| Acer pseudo platanus | June 23 | 4th to 6th leaf from end of branch | 3·3 | 8·3 | 0·030 | 0·016 | 11·8 |
| | June 24 | From base of branch | 3·58 | 40·0 | 0·058 | 0·026 | 5·2 |

| Species | Date | Description of leaves. | 10 gm. fresh leaves. | | Photosynthesis grm. $CO_2$ per hour. | | Photo-synthetic number $P_c$ |
| | | | Dry weight grms. | Chlorophyll milligram | Per 1 grm. dry weight | Per 1 sq. dm. leaf area. | |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Tilia cordata | June 25 | Young light green | 2·56 | 6·5 | 0·036 | 0·018 | 14·2 |
| | June 26 | Lower dark green from same branch | 3·19 | 28·1 | 0·058 | 0·028 | 6·6 |
| Laurus | June 30 | Light green leaves | 3·10 | 12·7 | 0·024 | 0·019 | 5·9 |
| Nobilis | July 1 | Dark green leaves of previous year | 4·95 | 21·2 | 0·023 | 0·023 | 3·7 |

The foregoing results of Willstätter and Stoll on the photosynthetic activity of leaves in different stages of development show that although the chlorophyll content of the leaves increases and the photosynthetic activity also increases, the two are not parallel. Consequently, it is clear that with the young leaves, the photosynthetic activity is exceedingly high and is not proportional to their chlorophyll content, because the respiratory activity of the young leaves is also very high. In other words, the greater the respiratory activity (metabolism), the greater is the photosynthetic activity.

The photosynthetic activity of etiolated plants in which the chlorophyll is just developing, shows the disproportionality between photosynthesis and chlorophyll content. Willstätter and Stoll, using cultures of *Phaseolus Vulgaris* and *Zea mays*, found that they are remarkably active, as soon as the first traces of chlorophyll are formed in light. Thus *Phaseolus* with a chlorophyll content of 0·7 milligram per 10 grams of fresh leaves, had a photosynthetic number $(P_c)=133$, whilst the control plants grown in light with 18·6 milligrams chlorophyll per 10 grams of leaves showed a photosynthetic number of 9·4. In general, the photosynthetic number of etiolated leaves is much higher than that of young leaves which developed in the light. This is certainly due to the fact that the respiratory activity of the etiolated leaves is much greater than that of young leaves which developed in the light.

### Influence of Iron Compounds on Plant Respiration

Moreover, the relation of photosynthesis and chlorophyll content of chlorotic plants is of great interest from this point of view. When plants grow in the absence of materials containing iron salts, they become very pale green or colourless

with limited development of chloroplasts. This happens even under conditions of high illumination intensity. It has already been emphasised that respiration is the most fundamental and vital of the plant processes and factors, which inhibit respiration, also interfere with normal development and growth of plants. It is well known that iron compounds are of great importance to respiration in the animal kingdom. Dhar and his collaborators have shown that food materials are readily oxidised by air or hydrogen peroxide in presence of iron compounds. The iron present in animal blood accelerates the metabolism of food materials in the body. Consequently when the iron content of the blood decreases or the amount of red blood corpuscles becomes less, metabolism of food materials becomes defective, and the person suffers from anæmia or chlorosis. Under these circumstances, iron compounds are used as medicine and these help metabolism.

In plant life also, in the absence of iron compounds, respiration becomes defective and hence the vital activities and growth of the plant are hindered and it becomes chlorotic and poor in chlorophyll content. As the respiratory activity is defective in chlorotic plants, it is expected that its photosynthetic power will also be anomalous. This is borne out from the experiments of Willstätter and Stoll, who cultivated plants with nutrient solutions containing no iron. While other types of leaves also poor in chlorophyll such as the light green or yellow varieties, autumnal and etiolated leaves, showed high photosynthetic activity in comparison with their chlorophyll content, the chlorotic leaves have a low rate of photosynthesis. Hence photosynthesis goes hand in hand with respiratory activity. It is interesting to note here the observations of Curtel (1900) who has reported that chlorotic plants have a lower rate of respiration and transpiration than normal plants.

The important fact brought out by the investigations of Willstätter and Stoll is that the leaves of light-green or yellow variety as far as photosynthesis is concerned, are affected more by differences in light intensity, while the leaves rich in chlorophyll are more sensitive to changes of temperature. These results have already been explained in the foregoing pages from our view-point of the opposing influence of respiration on photosynthesis.

In explaining these and other results Willstätter and Stoll have been led to the assumption of the existence of an internal factor or protoplasmic factor, which is supposed to be of an enzymatic nature. I have put forth the view that this internal factor is really the respiratory activity or metabolic activity of the plant, which is also probably of an enzymatic nature and may depend on the presence of inductors.

## INFLUENCE OF AGE ON PLANT PROCESSES.

It is a well established fact that metabolism (carbon dioxide output) per unit area decreases with age in the animal world. (Compare Dhar, New conceptions in Bio-chemistry, 1932.) In plant kingdom, the same relation is observed. From

the quantitative work of Willstätter and Stoll on the relations between the rate of photosynthesis, chlorophyll formation and respiration, it is clear that respiratory activity is very high in very young leaves and it decreases with time and development of the leaf. Young leaves have an exceedingly high rate of respiration, which decreases to one-fourth of this rate when the leaf matures. Kidd, West and Briggs (1921) have concluded from a large number of experiments on respiration of Helianthus annuus in the laboratory and in the field that the respiratory activity of the entire plant decreases with age. Hover and Gustafson (1926) have observed that the velocity of respiration of the leaves of maize, wheat, oat and sorghum also decreases with age up to middle age. In general, functional activity decreases with age. Under favourable conditions of temperature and light, the development of chlorophyll is rapid. Willstätter and Stoll have observed an increase in photosynthesis with an increase in chlorophyll content. There is, however, no direct proportionality between the chlorophyll content and the photosynthetic rate. This is shown in the following table:

Rate of photosynthesis, chlorophyll content and photosynthetic number at $25°$, 5% $CO_2$, about 48000 Lux-(results of Willstätter and Stoll).

| Date. | Species. | From 10 grms. fresh leaves. | | Photosynthesis gram $CO_2$ per hour. | | Photosynthetic number $Pc$ |
|---|---|---|---|---|---|---|
| | | Dry weight grms. | Chlorophyll milligrams. | Per grm. dry weight. | Per 1 sq. dm. | |
| April 29 ... | Aesculus Hippocastanum. | 2·10 | 10·1 | 0·054 | 0·043 | 11·1 |
| May 7 ... | | 2·06 | 15·1 | 0·088 | 0·039 | 12·1 |
| June 3 ... | | 2·94 | 24·7 | 0·054 | 0·033 | 6·4 |
| October 8 ... | | 3·62 | 31·2 | 0·041 | 0·044 | 4·8 |
| May 1 ... | Sambuscus Nigra. | 1·85 | 11·7 | 0·078 | 0·046 | 12·2 |
| May 8 ... | | 2·25 | 23·1 | 0·101 | 0·057 | 9·8 |
| July 14 ... | | 2·56 | 23·5 | 0·057 | 0·032 | 6·2 |

With time, the dry weight of the leaves increases and on the basis of the dry weight, there is a decrease in photosynthesis. The leaves also show a consistent increase in chlorophyll content but this does not involve an increase in photosynthesis. Similar results have been obtained with other leaves.

F. 7

It is well known that the longevity of cold-blooded animals is much greater than that of warm-blooded animals of the same size. Moreover, amongst warm-blooded animals, the longevity of smaller animals, is in general less than that of large animals. Also the duration of life varies inversely at the rate of energy expenditure during its continuance. In short, the length of life depends inversely as the rate of living. These results can be explained from the view-point that the greater the activity of the cells and the body enzymes the less is the duration of their active life. It has been frequently noted in catalytic operations that the duration of active catalytic influence of a highly active catalyst is short. (Compare Dhar—New Conceptions in Biochemistry, 1932.)

These conclusions appear to be applicable to the plant kingdom. In studying the influence of temperature on photosynthesis, it has been observed that the maximum velocity of photosynthesis cannot be maintained for a long time, but that with time, this maximum rate shifts to a lower temperature. This time factor is of great interest in plant physiology. In leaves poor in chlorophyll, *i.e.*, the light green or yellow varieties, the time factor appears more slowly than in leaves rich in chlorophyll. It has already been stated that chlorophyll rich leaves are more active towards photosynthesis and respiration than the yellow varieties of leaves. Hence the duration of the activity of the chlorophyll-rich leaves at a definite temperature is expected to be less than that of the comparatively inactive variety of leaves containing smaller amounts of chlorophyll. Consequently, the time factor appears more slowly in the less active yellow leaves than in the active chlorophyll-rich leaves. In other words, the activity of the chlorophyll-rich leaf will last for a shorter time than that of the chlorophyll-poor leaf.


## THE PHENOMENON OF "SOLARISATION"

It is well known that not only high temperature but also long exposure to strong light affects photosynthetic activity. Thus Ursprung (1917) observed that a leaf of *Phaseolus* after five hours of illumination showed very deep coloration of the starch iodine, while after 8·5 hours of illumination, the reaction was faint. This phenomenon can be observed with almost any source of light of sufficient intensity and the time required is proportional to the light intensity. The effect is first brought about in the red orange portion, the region showing the best photosynthetic activity. With higher intensity, the shorter wavelengths bring about in shorter time and it is apparently proportional to the photosynthetic activity of light. Ursprung has called this phenomenon "solarisation" as it is analogous to the phenomenon of solarisation observed in photographic plates under similar circumstances.

It is expected that not only with starch but with other carbohydrates, similar effect will be observed. This behaviour has been ascribed to the inactivation of chloroplasts. After long exposure to intense light, the plant organs are assumed

not to function, although they are not killed and on keeping in the dark for a period, again produce starch normally.

The inhibiting effect of long exposure to light of high intensity on photo-synthesis has long been studied by Ewart (1897) and the inhibiting effect has been ascribed to the destruction of chlorophyll. Pantanelli (1903) explains the fatigue effects observed by him in bright light from the view-points of chlorophyll des-truction and injury to the chloroplast plasma. The observations of Ewart on *Allium cepa*, which does not form starch, indicate that when leaves of this plant are exposed to bright light for 14 days or for a shorter period while being fed with sugar, the evolution of oxygen finally ceases. This inactivation apparently does not injure the cells or chloroplasts. After a few days in darkness, the capacity for photosynthesis is regained.

The foregoing facts are explained from the following considerations:

In plants the following equilibrium exists:
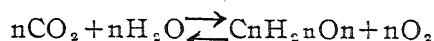
$$nCO_2 + nH_2O \underset{\longleftarrow}{\overset{\longrightarrow}{\rightleftharpoons}} CnH_2nOn + nO_2$$

The direct action (photosynthesis) is being opposed by the reverse reaction (respira-tion), which will increase, according to the law of mass action with increase in the concentration of the carbohydrate, which is a product of photosynthesis. Consequently with accumulation of carbohydrates or when the plants are fed with sugar, as was done by Ewart, photosynthesis is retarded and may stop altogether when the carbohydrate content becomes very high. When the illumination is high and it lasts for a long time, the carbohydrate content increases and along with it the respiration also increases, and thus the photosynthetic velocity falls off with time even when the illumination is continued. After a time, the res-piration will more than counterbalance photosynthesis and the carbohydrates formed by the photosynthesis will be oxidised to carbon dioxide and water and will disappear on prolonged exposure. When the carbohydrates dis-appear, the photosynthesis will again begin. It has been known for a long time that the photosynthetic rate decreases with accumulation of the products of photosynthesis. Moreover, Saposchnikoff (1893) has demonstrated the inhibitory power of an accumulation of carbohydrates and that these cannot increase beyond a certain point. When the leaves of *Vitis vinifera* contain 23 to 29 per cent carbohydrates of the dry weight, photosynthesis ceases and respiration predomi-nates. Saposchnikoff has shown that as carbohydrates accumulate, decrease of photosynthetic rate takes place, whilst a decrease in the carbohydrate content results in an increased photosynthesis. These results are evident from the view-point of the reversible reactions already put forward.

Moreover, there are two other factors, which increase respiration, should be considered: (1) influence of light intensity on the respiratory process, (2) influence of increased temperature caused by prolonged light absorption. In several publications, Dhar and collaborators have shown that food materials like starch,

sugars, proteins, fats, etc., in aqueous solutions or suspensions are oxidised to carbon dioxide and water by simply passing air at the ordinary temperature in presence of sunlight. In absence of light, there is no oxidation. In presence of inductors like ferrous hydroxide, cerous hydroxide, glutathione, insulin, etc., the food materials are oxidised to carbon dioxide and water by air even in absence of light. In presence of sunlight, these induced oxidations are greatly increased. Hence Dhar and collaborators have suggested that on light exposure the metabolism in the animal body is increased, because the food materials are oxidised to a great extent by air due to the absorption of light. It seems pretty certain that in plants also the respiration or the oxidation of carbohydrates and other food materials, which slowly proceeds in the dark due to the presence of enzymes and inductors, is accelerated on exposure to light. It is well known that several plants and flowers run a temperature higher than that of the surrounding air in the dark due to respiration and these may be roughly compared to warm-blooded animals. In the dark, most plants resemble cold-blooded animals as the plants do not possess thermo-regulatory contrivance as in warm-blooded animals, and the plants undergo oxidation and the carbohydrates and other food materials are burnt away. The temperature attained by plants is cumulative. The rise of temperature can be observed by pushing the arm in a heap of lawn cuttings containing a fair amount of clover. Moreover Molisch (1908) observed that the bulked leaves of *Carpinus betulus* attained a temperature of 51° in 15 hours. Pierce (1912) reported a heat gain due to respiration of 8·55 calories per minute per kilogram of germinating peas. The amount of heat generated by germinating peas decreases with age. It is of interest to note that the amount of heat energy generated by the germinating peas is roughly one quarter less than the quantity of heat evolved by a mouse under identical conditions.

In obtaining the energy necessary for its existence, the plant can show a much larger change of weight than the animal. Thus Ramann and Bauer (1911) have recorded that young saplings of deciduous trees show a decrease of 20 to 45 per cent of their dry weight during the period of activity following the winter sleep. It will be of interest to note that the respiratory exchange of hibernating mammals during the awakening is enormously greater than that during the period of sleep. In presence of strong light, the respiration velocity seems to be increased. Moreover when the plant is exposed to strong light for a long time, the temperature of the plant is likely to increase and with increased temperature, the respiration velocity is markedly increased, because the influence of temperature seems to be more pronounced on respiration than on photosynthesis. Consequently, when a plant is exposed to bright light for a long time, respiration more than counterbalances photosynthesis due to the increased concentration of carbohydrates, increased velocity of respiration by the absortion of radiant energy in the form of light and increase in the temperature of the plant by the absorption of light and the conversion of the light rays to heat. Under these circumstances, plants may behave as animals, as far as metabolism is concerned.

## COMPENSATION POINT.

The important facts regarding compensation point are as follows :—

The compensation point, *i.e.*, the light intensity at which the photosynthetic and respiratory activities of the plant compensate each other decreases with decrease of temperature as will be evident from the following table :—

Spirogyra 174 at 20°; 26'7 at 5° ; Fontinalis 150 at 20° ; 40 at 5° ; Cladophora-253'3 at 20° ; 62'9 at 5°; Cinclidotus 400 at 20 ; 75 at 5°. The foregoing results show that the light intensity which at 20° represented the compensation point, produced an evolution of oxygen due to photosynthesis at 5°.

With *Cladophora*, with increasing temperature, the compensation point rises more rapidly than the rate of respiration determined in the dark; an increase of temperature from 5° to 25° causes the respiration to become 4'8 times greater in the dark, whilst the light intensity increases to 6'69 times.

The foregoing results as well as other facts on the compensation point can be explained from the following considerations :—

1. Photosynthesis is proportional to the light intensity, there being no photosynthesis in the dark.

2. Respiration takes place in the dark but is appreciably accelerated by light.

3. An increase of temperature affects respiration more markedly than photosynthesis.

The fact that the compensation point rises with increase of temperature is due to the greater increase of respiratory activity than photosynthetic activity with increased temperature. The respiratory activity of the plant, which counterbalances the photosynthetic process, increases much more than photosynthesis at higher temperatures and consequently, the light intensity must be increased to cause more photosynthesis to counteract the increased respiratory activity. There is another reason for further increase in the respiratory activity of the plant. Hitherto, it has been assumed by most of the plant physiologists that the process of respiration is not accelerated by light. But it is evident from the researches of Dhar and collaborators that animal metabolism is markedly accelerated by light absorption. Hence, it seems pretty certain that the respiratory process taking place in plants is also accelerated by light. Consequently, the respiratory activity of the plant is accelerated by two agencies; *e.g.*, temperature and light intensity and thus the light intensity required for increased photosynthesis in order to counteract this high respiratory activity should be very high. Thus with increasing temperature, the compensation point should rise more rapidly than the rate of respiration because of its additional enhancement by light absorption and this is clearly borne out from the experiments on *Cladophora* in which an increase of temperature from 5° to 25° causes the respiration to become 4'8 times greater when determined in the dark, whilst the light intensity increases 6'69 times, for the compensation point.

It is evident that under certain circumstances, when the temperature is high and the light is intense, the compensation point may not be attained even with intense light and the plant will evolve carbon dioxide like an animal even in presence of light. This is likely to happen frequently in tropical countries where at the sea level, the heat rays of the sun become very prominent and the temperature of the plant will be high and photosynthesis cannot counterbalance respiration under these circumstances. At higher altitudes, the light rays are more active than at the sea level and it is expected that at these altitudes, very seldom, respiration will exceed photosynthesis in sunlight. These conclusions are corroborated from the experimental results of Harder (1921) with sea plants in the polar zones where the light intensity is not very high. Thus Harder records the following ratio of $\frac{\text{photosynthesis}}{\text{respiration}}$ for different temperatures:—

$$20°-22°\quad 0\cdot5882\quad 0\cdot4427\quad 0\cdot4280$$
$$2°-3\cdot5°\quad 1\cdot603\quad 0\cdot9207\quad 2\cdot059$$

The position of the compensation point of a plant with reference to temperature is naturally of great importance to the life of the plants and its relation to the environment.

Harder has reported that conditions may exist in nature where at higher temperatures, the plant stores no material through photosynthesis on account of the high respiratory activity. While at lower temperatures with the same light intensity, food materials are formed in the plant by photosynthesis.

The experimental observation that the compensation point, (i.e., the light intensity at which the photosynthetic and respiratory activities of the plant compensate each other varies with different plants) is explained on the basis that the respiratory activity of the plant and its increment by temperature and light vary with different plants.

Starting with the same culture of *Cladophora*, and keeping one portion in diffused light and another in direct sunlight, great differences in the compensation point are observed in a week. With *Sinapis alba*, a plant growing in light, the compensation point is at 1·0 (Bunsen units × 100) but a compensation point lying at only 0·2 is observed with *Oxalis aceto-sella*, a shade plant. Previous illumination of the plant must be considered before any conclusion is drawn from determination of the compensation point, which varies considerably with previous illumination of the plant. It has been observed that under certain circumstances, in *Fontanalis*, photosynthesis more than counterbalances respiration when the illumination is only 10 lux, whilst under other conditions, 150 lux is insufficient to achieve this.

Under constant and high illumination, leaves of beach tree emits carbon dioxide at 6250 lux; the sun tree, *Robina*, requires 25 times more intense light for photosynthesis to exceed respiration than the shade tree *Fagus*. According to Lundegardh (1921) the respiration of the shade plant *Oxalis* is lower than that in

the sun plants *Nasturtium* and *Atriplex*.   In *Oxalis*, the compensation point occurs in normal air at a light intensity of 1/120 to 1/140 that of direct sunlight; whilst in the sun plants, the compensation point is attained when the light intensity varies from 1/40 to 1/60 of direct sunlight.

These experimental observations are explicable from the following consideration:—The temperature of the trees growing in light is higher than that of trees growing in the shade.   Hence, the respiratory activity of plants growing in shade is much less than that growing in light.   Moreover, the respiration of plants growing in light is also accelerated by the light absorption.   Consequently the light intensity required to cause the increased photosynthesis in order to counteract the enhanced respiration due to an increase of temperature and light absorption must be very high.

Moreover, there is another important consideration in the explanation of the higher compensation point of trees grown in light than in the shade.   From our experience on the velocity of photochemical reactions taking place in strong light, it is generally observed that the velocity of the photochemical reaction is not directly proportional to the light intensity or the absorbed light but the velocity varies as $I^n$ where $n$ is less than unity.   On the other hand, in presence of feeble light also the velocity varies as $I^n$, in which case $n$ is unity or more.   Consequently, from the quantitative experiments with ordinary photochemical reactions, it is clear that in presence of intense light, photochemical reactions utilise less amount of absorbed radiation than when the same reactions take place in less intense light.   This is usually known as "exhaustion effect".   It is clear, therefore, that in photosynthesis, the same relation is to be expected.   This behaviour has been observed by O. Warburg (1922) in his experiments on the efficiency of the photosynthetic process. It has been reported by Warburg that when plants are cultivated under conditions of high light intensity, they utilise only a small amount of the absorbed energy. Plants grown under conditions of low light intensity can utilise a relatively large proportion of the absorbed energy.   Hence the light intensity necessary to obtain the requisite velocity of photosynthesis required to counteract respiration in the case of plants growing in light will be greater than that required for plants cultivated in the shade.   Hence by growing the same type of plant under conditions of high and low light intensity, one type apparently passes into the other within a short time and its photosynthetic efficiency and possibly respiratory activity are altered.

From the foregoing pages, it is clear that the contention of Plaetzer (1917) that the value of the light intensity at the compensation point is not a function of the respiratory activity is not correct.   Plaetzer in his consideration of the compensation point missed the important point that the respiratory activity is also accentuated by light.

From these considerations, one thing comes out very prominently that respiration is of vital importance to plant and is more fundamental and important

to plant life than photosynthesis, which predominates in the plant only under highly restricted conditions of temperature and light intensity. In other conditions beyond this limit, in light as well as in the dark, plant life enjoys respiratory activity as much as animal life. Hence it appears that respiratory activity controls plant life as animal life.

# CHEMICAL EXAMINATION OF THE FRUITS OF *TRIBULUS TERRESTRIS*, LINN.

## BY NARENDRANATH GHATAK

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*Tribulus terrestris*, commonly known as small caltrops in English, *chota-gokhru* in Hindi and *gokhuri* in Bengali, is a plant of the natural order Zygophylleæ. It is a well-known medicinal plant of long use in Hindu medicine. 'It has a slender fibrous root 4-5 inches long, cylindrical and of a light brown colour; the odour is faintly aromatic and the taste is sweetish and astringent. From the roots spring 4 to 5 delicate stalks, spreading on the ground; these are hairy and extend to $2\frac{1}{2}$ ft. in length ; the leaves are pinnated, leaflets of 5 to 6 pairs, nearly round. The flowers are auxiliary on short peduncles and composed of five broad obtuse yellow petals; these are succeeded by a roundish five-cornered fruit, about the size of a marble, armed with prickles ; this ripening divides into five cells, each armed with four strong thorns and containing several seeds. The seeds are oily, and enclosed in very hard stony cells. The plant is common in sandy soil throughout India, and is found plentifully in the United Provinces and in Madras. The matured fruits are sun dried and stored for medicinal uses.

As regards its medicinal properties the Hindus[1] consider the fruit and root as having cooling, diuretic, tonic and aphrodisiac properties; and use them in gonorrhœa and dysuria. It[2] is used in painful micturition, calculous affections, and impotence. *Tribulus terrestris* attracted the attention of European[3] doctors and has been favourably spoken of by them as an aperient and diuretic. An infusion made from the frint has been found very useful in gout, kidney disease and gravel.

As regards its chemical properties an ethereal or alcoholic extract of the powdered fruits are supposed to yield to water a crystalline residue containing a body precipitated from its solution by ammonia and having the properties of an alkaloid and associated with hydrochloric acid or alkaline chlorides. The fruits also contain a fat and a resin, the latter is probably the source of aroma of the drug, as it gives off a fragrant odour when burnt. The fruits contain a rather large quantity of mineral matter (14·9%).

The above represents the work that has been done on the plant. The present author was tempted to put the fruits under systematic chemical analysis on account of

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the crystalline alkaloid supposed to be contained in the plant. Unfortunately, the claims in this direction, put forward by previous workers, could not be substantiated, as will be seen in the experimental part of the paper. The investigation on the fruits has, however, proved the presence of 5 per cent of a pale-yellow semi-drying oil, a peroxidase and a starch hydrolysing enzyme, traces of a glucoside body, large quantity of inorganic matter, a resin, a nitrogenous protein compound and a phlobaphene. The results of examination are recorded in the experimental part of the paper.

## EXPERIMENTAL.

The dried fruits of *Tribulus terrestris* were obtained from local market. A preliminary experiment was made with the cold hydrochloric acid extract of the powdered drug with alkaloidal reagents, and the following precipitates were obtained:—

|  |  |
|---|---|
| Picric acid ... ... ... | yellowish-white turbidity. |
| Sodium carbonate ... ... | White gelatinous precipitate. |
| Phosphomolybdic acid ... | White preeipitate. |
| Mayer's reagent ... ... | do. |
| Phosphotungstic acid ... | do. |
| Dragendorff's reagent ... | orange brown precipitate. |
| Bouchardat's reagent... ... | brown precipitate. |
| Platinic chloride ... ... | yellowish white precipitate. |
| Gold chloride ... ... ... | precipitate in traces. |

None of the above precipitate was crystalline. An aqueous extract of a fresh quantity of the drug, however, remained unaffected by the above reagents.

500 c.c. of 2 per cent. hydrochloric acid extract of 200 g. of the powdered material was made alkaline with ammonia. The precipitate was filtered and identified to be inorganic. The filtrate was separately extracted with petroleum ether, chloroform and amyl alcohol, but nothing was extracted by the solvents. The aqueous solution was made acidic and again alkaline with caustic soda. The precipitate which was of a yellowish colour was again inorganic. The filtrate did not give anything of an alkaloidal nature on extraction with the organic solvents in succession as before. The original extract on concentration and heating with alkali hydroxide, developed ammonia, and it also yielded precipitates with the usual alkaloid reagents. These reactions were evidently due to soluble protein products, since the alkaline liquids, when extracted with either petroleum ether, chloroform or amyl alcohol, yielded nothing of a definite alkaloidal nature.

The fruits contained 7˙86 per cent moisture and when completely burnt left 11˙41 per cent of a white residue. The ash contained 20˙95 % of water soluble and 79˙05 % of water insoluble inorganic substances. The ash contained the following

positive and negative radicals:—potassium, calcium, iron, aluminium, magnesium, silicic acid, chloride, phosphate, nitrate and sulphate (the last two in traces).

*Test for enzymes :*—100 g. of the powdered drug was kept in a flask with 300 c.c. distilled water containing 3 c.c. of toluene for 48 hours at room temperature. It was filtered at the pump and the filtrate, which was of a yellow colour, was tested for enzymes.

(*i*) In each of three test tubes 10 c.c. of one per cent soluble starch solution was kept and to the first tube 10 c.c. enzyme solution, to the second 10 c.c. boiled enzyme solution and to the third 10 c.c. distilled water was added respectively and kept over night. The first tube containing enzyme solution reduced Fehling's solution immediately on slight heating while the other two remained unchanged with the same treatment. This behaviour of the first tube proved the presence of a starch hydrolysing enzyme in the fruits.

(*ii*) To a cooled (10°C) mixture of of 65 c.c. water, 20 c.c. of 5 per cent pyrogallol and 20 c.c. of one per cent hydrogen peroxide was added 10 c.c. of the enzyme solution. In about an hour sufficient quantity of brown precipitate was formed, whereas the control experiments remained unaffected. The precipitate was filtered and was proved to be purpurogallin by its characteristic colour reactions. Thus the fruits contain a peroxidase.

The presence of a peroxidase was also established by adding 10 c.c. enzyme solution to a mixture of 10 c.c. saturated solution of hydroquinone and 10 c.c. 1% hydrogen peroxide, when dark green lustrous slender needles of quinhydrone were formed after about ten minutes. The control experiments remained unaffected. Both the quinhydrone and purpurogallin reactions could not be repeated in the absence of hydrogen peroxide, which shows the absence of oxidase. A detailed study of the peroxidase will be given in a separate communication.

For complete analysis 2 kilogrammes of the powdered fruit were exhaustively extracted with petroleum ether. The extract on complete distillation of the solvent gave 98 g. of a greenish yellow oil of a dark colour. The purification and the constitution of the oil is described separately. The petroleum ether extracted powder was extracted with rectified spirit till the colour of the extract became very light. The extract was brown in colour with a green fluorescence. It was concentrated and the liquid on standing deposited shining white crystals which was identified to be pure potassium chloride and weighed 9·6 g. The filtrate was further concentrated to a volume of about 300 c.c. Water was added and a yellowish-brown paste separated. The filtrate which was a yellowish brown colour gave a yellow precipitate on addition of lead acetate solution. The lead salt was purified and decomposed in aqueous suspension by $H_2S$. After removal of the lead sulphide, the mother liquor was evaporated when a brown syrupy mass was obtained. It is constituted mostly of tannins as it gave a greenish-black coloration with neutral ferric chloride solution. The filtrate of the above lead salt gave a second yellow

precipitate with basic lead acetate solution. This precipitate on decomposition with $H_2S$, as in the previous case, gave a small quantity brown sticky residue on complete evaporation. It was very soluble in water and reduced Fehling's solution only after being hydrolysed with hydrochloric acid. The substance in alcohol solution developed a purple-violet ring on addition of a few drops of a 20 % α-naphthol in alcohol and afterwards a layer of concentrated sulphuric acid. This substance is therefore a glucoside; but on account of its not yielding to any of the methods of crystallization, it could not be further investigated.

The pasty precipitate that was obtained by addition of water to the concentrated alcoholic extract was thoroughly washed with water and on standing overnight became brittle and weighed 25 g. It was freed from oily contamination with petroleum ether. The product thus obtained was of a brownish yellow colour, contained nitrogen and melted at about 98°C. This on extraction with ether and complete evaporation of the solvent gave a resinous mass having the characteristic odour of the powdered drug. The ether insoluble portion dissolved in alkali and was reprecipitated with the addition of mineral acids. In alcoholic solution it produced a yellow precipitate and also gave a greenish-black coloration with ferric chloride. On boiling with hydrochloric acid a brick red mass was obtained which melted at 108°C. The substance was therefore a phlobaphene.

The alcohol extracted drug was freed from alcohol and was extracted with 2 % cold hydrochloric acid. The filtrate was completely precipitated with excess of Mayer's reagent. The dirty white precipitate was decomposed by $H_2S$ in alcoholic suspension. The filtrate was freed from $H_2S$ and on complete evaporation gave yellowish white residue. This substance melted at 189—91°C and on heating evolved ammonia along with a pungent fume of burnt proteins. It also responded to the biuret reaction. This was the substance which gave the precipitates with alkaloidal reagents when the crude drug was extracted with dilute hydrochloric acid.

## EXAMINATION OF THE OIL

The crude oil was digested with animal charcoal and filtered through a hot filtering funnel. The purified oil was freed from last traces of petroleum ether by heating over water bath and finally in a vacuum desiccator. The oil, which was of a pale yellow colour, on standing overnight deposited a small quantity of white crystalline mass. It was filtered and the precipitate was put on a porous plate. After few days the substance became perfectly white. It was insoluble in cold alcohol but dissolved in it on boiling. The crystallised product melted at 83°C. and weighed 0·17 g. It formed a white lead salt with alcoholic solution of lead acetate and was an aliphatic acid. This substance was confirmed to behenic acid by its lead salt. [Found Pb = 24·2%, behenic acid lead salt $C_{44} H_{86} O_4Pb$, requires Pb = 23·4 %]

The oil does not contain nitrogen and sulphur. It is optically active, having a small lævo rotation $\left[\alpha\right]_{D}^{25} = -0\overset{.}{5}7$. The fatty acids obtained after saponification of the oil is optically inactive, which shows definitely that the rotation is due to the unsaponifiable matter. The oil burns with a non-sooty, odourless flame and gives a positive reaction for phytosterols. In order to test the drying power of the oil, few drops of it was spread on a clean glass plate and kept at room temperature. After a fortnight the oil became sticky, proving it to be of the class of semi-drying oils. The physical constants of the oil are given in Table I.

*Table 1.*

| | | |
|---|---|---|
| Specific gravity at 25°C | ... | 0˙9148 |
| Refractive index at 20°C | ... | 1˙4734 |
| Solidifying point | ... | 3°C |
| Acid value | ... | 42˙17 |
| Saponification value | ... | 184˙9 |
| Acetyl value | ... | 48˙03 |
| Iodine value | ... | 131˙3 |
| Unsaponifiable matter | ... | 1˙08 |
| Hehner value | ... | 96˙2 |

Seventy grammes of the oil was subjected to distillation with steam in a 500 c.c. flask. The first 200 c.c. of the distillate was extracted with ether. The ether layer was separated, dried with anhydrous sodium sulphate and on evaporation left no oily residue—proving the absence of volatile oil. The oil was next saponified with alcoholic potash and the unsaponifiable matter was removed with ether in the usual way. The soap solution was dissolved in excess of water and decomposed with dilute sulphuric acid in presence of petroleum ether. The petroleum ether-fatty acid layer was washed free from traces of sulphuric acid in a separating funnel. The mixture of fatty acids was next freed from moisture with anhydrous sodium sulphate, filtered and petroleum ether was distilled off. Table II gives the analytical constants of the fatty acids separated from the oil.

*Table II.*

| | | |
|---|---|---|
| Specific gravity at 25°C | ... | 0˙8978 |
| Refractive index at 20°C | ... | 1˙4721 |
| Iodine value | ... | 135˙6 |
| Neutralisation value | ... | 187˙9 |
| Mean molecular weight | ... | 298˙6 |

The mixture of the fatty acids were then separated into saturated and unsaturated acids by (i) lead-salt-ether method and (ii) Twitchell's lead-alcohol

method. The separation of the saturated and unsaturated acids is more quantitative by the second method as is apparent from the iodine values of the saturated acids. In the experiment with Twitchell's method of separation 20 g. of the fatty acids isolated previously was dissolved in 500 c.c. of 95 per cent ethyl alcohol. The solution was boiled and to it was added a boiling solution of 250 c.c. alcohol containing 13 g. lead acetate. The mixture was kept at room temperature (21°C.) overnight and the precipitated lead salt was filtered and washed free of lead with alcohol. The precipitate was again dissolved in 200 c. c. boiling 95% alcohol containing 1 g. acetic acid and the solution cooled overnight. The precipitate was filtered, purified and decomposed with dilute nitric acid in ethereal solution. The ether solution was washed free of nitric acid, dried and the solid acid was recovered. The mixture of the filtrate of the insoluble lead salt and washings was concentrated to 75 c.c. Water was next added to it and the lead salt was decomposed with dilute nitric acid and the liquid acids isolated as before. Table III gives the percentage of saturated and unsaturated acids as estimated by two methods.

*Table III.*

|  | Percentage of unsaturated acid. | Percentage of saturated acid. | Iodine value of saturated acid. |
| --- | --- | --- | --- |
| (i) Lead-salt-ether method ... | 81·67 | 18·33 | 40·62 |
| (ii) Lead-salt-alcohol method ... | 83·81 | 16·19 | 3·08 |

UNSATURATED ACIDS

*Elaidin test for the liquid acid.*—1 g. of the liquid acid was treated with 5 c.c. of nitric acid and 0·6 g. of sodium nitrite was added in small portions and was allowed to stand in a cool place. After some time the acid solidified. The product was next pressed on a porous plate and the resultant solid, when crystallised from ether, melted at 44-45°C. and was identical with elaidic acid.

*Oxidation of the unsaturated acids with potassium permanganate solution.*— 10 g. of the acids were oxidised with 2 per cent potassium permanganate in alkaline solution at room temperature with constant stirring. After the reaction a current of sulphur dioxide was passed through the solution to dissolve the precipitated manganese dioxide. The insoluble white substance was filtered and extracted with ether. The ethereal extract, after the removal of the solvent, deposited a product, which on crystallisation from alcohol melted at 134-35°C., and was identified to be dihydroxy-stearic acid. The formation of this acid proved the presence of oleic acid in the liquid acids. The ether insoluble portion of the oxidation product was extracted with boiling water and the filtrate on concentration and cooling deposited crystals, which on drying melted at 164-65°C., and was identified to be tetrahydroxy-stearic acid (sativic acid). The formation of this acid proved the presence of linolic acid in the oil. No hexahydroxy stearic acid could be

isolated from the oxidation product which proved the absence of linolenic acid in the liquid acids.

The iodine value of the mixture of the unsaturated acids was found to be 151·9. Therefore, the proportion of oleic and linolic acids in the unsaturated acids was calculated with the help of the following equations:—

$$X + Y = 100.$$
$$90·07X + 181·14Y = 100 \times I.,$$

where    $X$ = the percentage of oleic acid,

       $Y$ = the percentage of linolic acid,

   and I = the iodine value of the mixture of unsaturated acids.

Table IV gives the percentage of oleic and linolic acids calculated from the above equations.

*Table IV.*

|  | Percentage in the unsaturated acids. | Percentage in the total fatty acids. | Percentage in the original oil. |
|---|---|---|---|
| Oleic acid   ... | 32·11 | 26·91 | 25·88 |
| Linolic acid   ... | 67·89 | 56·89 | 54·73 |

The constituents of the unsaturated acids were also estimated by means of their bromine addition products as recommended by Jamieson and Baughmann[*]. Accordingly, a known weight of the unsaturated acids was dissolved in 130 c.c. of dry ether and was cooled in a freezing mixture to —10°C. and dry bromine was added slowly drop by drop till it was in excess. During the addition of bromine, the temperature of the liquid was kept below — 5°C and the mixture was kept for two hours at —10°C. No precipitate was obtained. The ethereal liquid was then freed from excess of bromine with an aqueous solution of sodium thiosulphate in a separating funnel. The solution was then dried with anhydrous sodium sulphate, filtered and the ether distilled off. The residue was dissolved in 150 c c. dry petroleum ether with boiling and the flask was put in the ice-chest overnight. The precipitate of the tetrabromo linolic acid was filtered, washed and dried The filtrate and washings was concentrated to 60 c.c. and again kept in the refrigerator overnight. The second crop of the precipitate was added to the first and weighed. It melted at 113-14°. The filtrate was concentrated to 30 c.c. and again kept as before, but this time no precipitate was formed. Finally the petroleum ether was completely removed and the precipitate weighed and its bromine content was determined. The residue on extraction with hot methyl alcohol gave a further quantity of tetrabromo compound. The following table contains the data of the analysis of the bromo derivatives.

*Table V.*

Weight of the unsaturated acid taken            ...         ...         ...     4·7347 g.
Linolic acid tetrabromide insoluble in petroleum ether ...         ...     3·3784 g.
Residue ( dibromide and tetrabromide )         ...         ...         ...     5·8050 g.
Bromine content of the residue     ...         ...         ...         ... 46·2257 %.
Dibromo oleic acid in the residue ...         ...         ... (41·37%) or 2·4015 g.
Tetrabromo linolic acid in the residue         ...         ... (58·63%) or 3·4035 g.
Total tetrabromo linolic acid found            ...         ...         ...     6·7819 g.
Linolic acid equivalent to tetrabromide        ...         ...3·1640 g. or 66·83     %.
Oleic acid equivalent to dibromide             ...         ...1·5320 g. or 32·36     %.

Table VI gives the percentage of oleic and linolic acids in the unsaturated acids as calculated from the above data.

*Table VI.*

|                  | Percentage in the unsaturated acids. | Percentage in the total fatty acids. | Percentage in the original oil. |
|------------------|:---------:|:---------:|:---------:|
| Oleic acid    ... | 32·36 | 27·12 | 26·08 |
| Linolic acid  ... | 66·83 | 56·01 | 53·88 |

## SATURATED ACIDS.

The saturated acids, separated by the lead-salt-alcohol method, was freed from traces of liquid acids by pressing over porous plate. The acid thus obtained melted between 53–56°. It was dissolved in alcohol and precipitated by diluting with water in three instalments; but none of the portion on drying gave definite melting points. The quantity of the saturated acids being too small, it could not be separated into its constituents. Utmost that could be done was to confirm the presence of palmitic and stearic acids by qualitative experiments according to the methods of Kreis and Hafner[5], and Hehner and Mitchell.[6]

My best thanks are due to Dr. S. Dutt for the kind interest he has taken in the work and to the 'Kanta Prasad Research Trust' of the Allahabad University for a scholarship which enabled me take part in the investigation.

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# PEROXYDASE FROM THE FRUITS OF *TRIBULUS TERRESTRIS*, LINN.

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In a previous communication,[1] on the chemical examination of the fruits of *Tribulus terrestris*, or *Chota Gokhru* as it is known in Hindi and small caltrops in English, a reference was made of the presence of a good quantity of peroxydase in the fruits. The fact that the fruits are widely used as a good tonic and blood purifier interested the present authors for a detailed and systematic study of the enzyme which is most probably responsible for the alleged physiological properties of the drug. The fruits of the plant are found to be a good source for the enzyme. The plant grows in abundance in the waste sandy soil throughout India. The present paper deals with the various factors affecting the activity of the peroxydase of the extract prepared from the crushed fresh fruits of the plant.

## Experimental

Fresh fruits of *Tribulus terrestris* were washed and crushed well in a porcelain mortar and 500 g. of the crushed material with 1500 c.c. of distilled water and few c.c. of toluene were kept in a big flask for a day in the '*Frigidaire*'. The pulp was first cloth filtered and next transferred to a hand-screw press, and the sap expressed as completely as possible by applying pressure. The filtered and expressed solution thus obtained amounted to 1600 c.c. The extract was then filtered through

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paper pulp into a Jena glass bottle, toluene was added and kept in the refrigerator at 0°C. The activity of the solution remained unchanged even after three weeks.

A portion of the extract was dialysed through a parchment bag in a tall beaker at 15°C for five days against distilled water to which toluene had been added. The water was frequently replaced every day. After dialysis the solution was filtered to free it from suspended impurities into a Jena glass bottle containing toluene and preserved in the refrigerator   An extract prepared in this way retained its activity for a long time.

The peroxydase activities were determined by a method based on that described by Luther and Leubner[2] and Dey and Sitharaman[3]. The method briefly consists in precipitating and filtering the quinhydrone formed when the peroxydase acts on hydroquinone in presence of hydrogen peroxide, dissolving the precipitate in alcohol and titrating the iodine liberated with standard thiosulphate when a mixture of alcohol (20 c.c. 95%), concentrated hydrochloric acid (20 c.c.) and potassium iodide (20 c.c. of 10%) was added to the alcoholic extract of the quinhydrone.

The activities are always expressed in terms of c. c. of N/10 thiosulphate.

It is interesting to note that the activity of the peroxydase was not impaired on dialysis for five days. 200 c. c of the extract was dialysed for five days and the volume was made up to 800 c.c. This was again diluted with its own volume of water for the estimation of peroxydase activity in all the subsequent experiments. A similar extract was kept at the same temperature and diluted to the same extent and finally the activities of both the dialysed and undialysed extracts were compared.

To 10 c.c. of Walpole's acetate buffer of $P_H$ 5·3 was added 0·4 g. of hydroquinone and 10 c.c. of 2% by volume of $H_2O_2$ and finally 10 c.c. of the enzyme solution (total volume 40 c.c.). The reaction was carried at 15°C. for 15 minutes, and was stopped by adding 3 c.c. of 2N-HCl.

|  | Activity in terms of c.c. of N/10 thiosulphate. |
|---|---|
| Dialysed solution, | 10·80;  10·95. |
| Undialysed solution, | 11·50;  11·65. |

## Effect of Concentration of the Peroxydase on its Activity.

Since the extract was found to contain peroxydase in very concentrated form, it was necessary to choose a proper concentration of the enzyme, in order to study the course of the reaction of the enzyme on the substrate. Experiments were, therefore, carried out with extracts containing varying amounts of the enzyme. The reaction mixture consisted of 0·4 g. of hydroquinone, 10 c.c. of 2 per cent by volume of hydrogen peroxide and 10 c.c. of undialysed enzyme solution (Total volume 30 c.c.). The reaction was carried at 15°C and was stopped by the

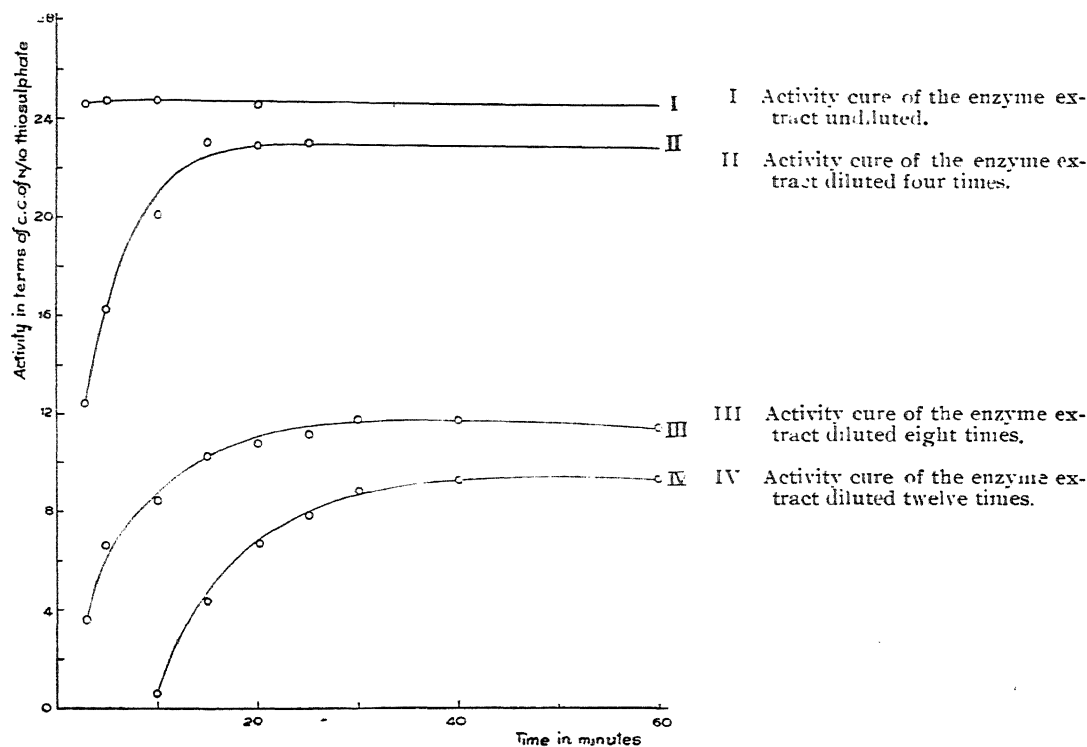addition of 3 c.c. of 2 N-HCl at required intervals. The results have been presented in Table I and Fig I.



I   Activity cure of the enzyme extract undiluted.

II   Activity cure of the enzyme extract diluted four times.

III   Activity cure of the enzyme extract diluted eight times.

IV   Activity cure of the enzyme extract diluted twelve times.

Fig. 1

### Table 1.

| Time in minutes | | 3 | 5 | 10 | 15 | 20 | 25 | 30 | 40 | 6.0 |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | N/10 Thiosulphate in c.c. | | | | | | |
| Undiluted extract | ... | 24·65 | 24·75 | 24·70 | ... | 24·65 | ... | ... | ... | ... |
| Diluted four times | ... | 12·40 | 16·20 | 20·15 | 23·05 | 22·95 | 23·00 | ... | ... | ... |
| Diluted eight times | ... | 3·55 | 6·60 | 8·55 | 10·30 | 10·80 | 11·20 | 11·80 | 11·80 | 11·45 |
| Diluted twelve times | ... | ... | ... | 0·55 | 4·30 | 6·80 | 7·85 | 8·85 | 9·30 | 9·50 |

In Fig. I the series of curves represent the increase in the amount of quinone formed, as measured by c.c. of thiosulphate, in hydroquinone solution under the action of various relative amounts of the same enzyme solution. Several things are to be noticed in these curves. These curves indicate in a general way the rate of change at the earlier stage of the reaction is proportional to the concentration of the enzyme, as is seen in the relative steepness of the curves. It may be noted that the curves II, III and IV do not reach to such a height as that of the curve I. This is due to the destruction of the enzyme in the course of its action on the substrate

In the experiments of Herzog and Meier˙ similar observations were made. They noticed that there is a relationship between the amount of oxidation brought about by a given quantity of hydrogen peroxide. This is attributed to the

destructive action of the peroxide on the enzyme, since the latter was found to be absent at the end of the reaction, when small amounts were added. Similar behaviour was observed of other enzymes with regard to the final result. Bayliss[5] has observed in the case of trypsin that the enzyme is destroyed in the course of its action on the substrate, when the concentration of the enzyme is selectively low. Some enzymes, however, withstand the destruction in the course of its action on the substrate and remains unaltered at the end of the reaction. Starkenstein[6] has shown that amylase remains unaltered at the end of the reaction and that it can act upon a further supply of substrate.

The enzyme concentration corresponding to the curve III was chosen for all other experiments since it can be found from the results that a dilution corresponding to $\frac{1}{8}$th of the enzyme concentration of the undiluted extract works most satisfactorily. A 15 minutes reaction period and 10 c.c. of the diluted enzyme which was found to be most suitable under the conditions of our experiments were chosen for all other experiments The reaction was always carried at 15°C.

### The influence of $P_H$ Upon the Activity of the Peroxydase.

The reaction mixture consisted of 0·4 g. of hydroquinone, 10 c.c. of 2% hydrogen peroxide, 10 c.c. of enzyme solution and 10 c.c. of buffer of varying hydrogen-ion concentrations (total volume 40 c.c.). Walpole's acetate buffer, providing a range of
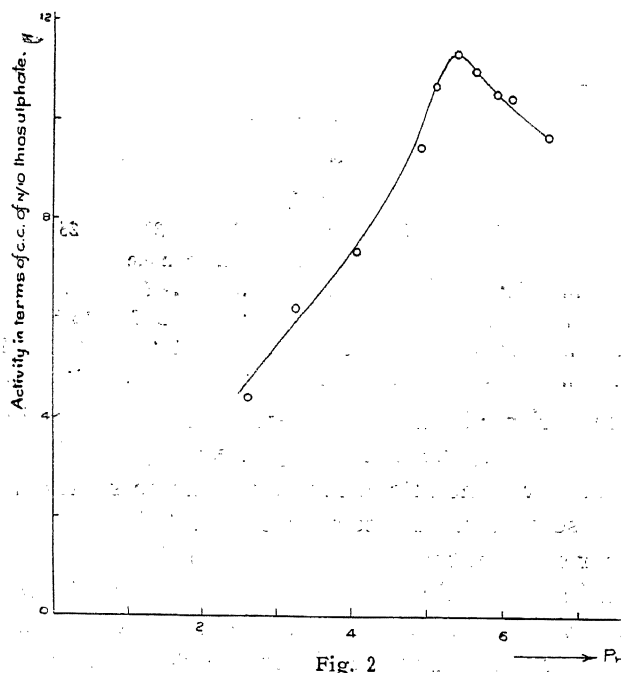


Fig. 2

$P_H$ 2·6 to $P_H$ 6·5 was used to maintain the $P_H$ of the medium. The reaction was carried at 15°C. for 15 minutes and stopped by adding 3 c.c. of 2 N-HCl.

The results are presented in Table II and Fig. II.

*Table II.*

| PH ... | 2·6 | 3·2 | 4·0 | 4·8 | 5·0 | 5·3 | 5·5 | 5·8 | 6·0 | 6·5 |
|---|---|---|---|---|---|---|---|---|---|---|
| N/10 thiosulphate in c. c. | 4·50 | 6·30 | 7·45 | 9·60 | 10 80 | 11 50 | 11·15 | 10·70 | 10·65 | 9·85 |

The results indicate that the maximum activity of the peroxydase lies between PH 5·3 and 5·5 in the acid region

## Effect of hydrogen peroxide concentration on peroxydase activity

Bach[7], Willstater and Weber[5], Mann[9], Dey and Sitharaman[3] have shown that excess of hydrogen peroxide inhibits the activity of peroxydases. It was, therefore, necessary to determine the proper concentration of hydrogen peroxide to be employed in each experiment.

Several experiments were made in which the concentration of hydrogen peroxide was varied, while all other factors were kept constant. The reaction mixture consisted of 0·4 g. of hydroquinone, 10 c. c. of buffer (PH 5.3), 10 c. c. of hydrogen peroxide of varying concentrations and 10 c.c. of the enzyme solution
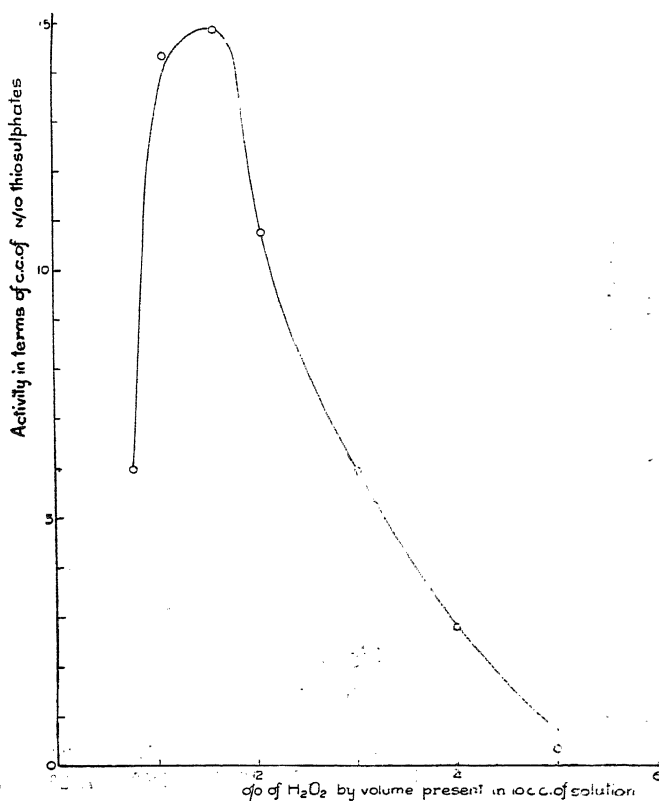


Fig. 3

(Total volume 40 c. c.) The reaction was carried for 15 minutes at 15°C. The results are given in Table III and Fig. III.

*Table III.*

| Percentage by volume of $H_2O_2$ in 10 c.c. ... | 7·5 | 5·0 | 4·0 | 3·0 | 2·0 | 1.5 | 1·0 | ·75 | 0·5 |
|---|---|---|---|---|---|---|---|---|---|
| N/10 thiosulphate in c. c. ... ... | 0·35 | 2·80 | 5·95 | 10·75 | 14·85 | 14·30 | 5·90 | .. | |

It can thus be seen that under the conditions of our experiments, the maximum activity is attained with 1·5 per cent of hydrogen peroxide.

### Effect of concentration of Substrate upon the action of the peroxydase

A series of flasks containing 10 c.c. of hydrogen peroxide (1·5%), 10 c.c. of buffer (PH 5·3), 10 c.c of enzyme solution and hydroquinone of varying concentrations in 10 c.c. were taken and reactions were carried for 15 minutes at 15°C. The results are presented in Table IV and Fig IV.
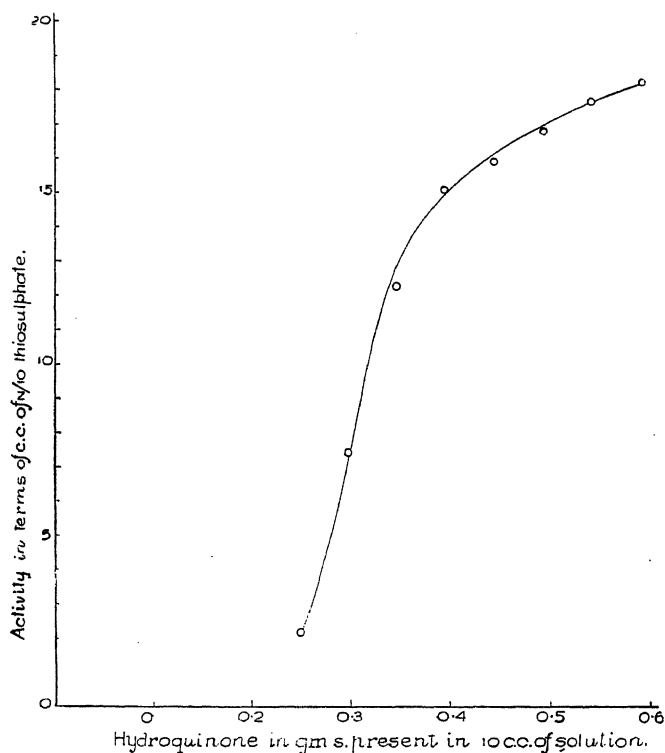


Fig. 4

*Table IV.*

| Wt. of Hydroquinone in gram in 10 c.c. of water ... | ·60 | ·55 | ·50 | ·45 | ·40 | ·35 | ·30 | ·25 | ·20 |
|---|---|---|---|---|---|---|---|---|---|
| N/10 thiosulphate in c.c ... | 18·05 | 17·50 | 16·70 | 15·80 | 15·00 | 12·20 | 7·45 | 2·05 | ... |

The curve in Fig IV shows that the activity of the enzyme is increased with the increase in concentration of the substrate. At higher concentrations, however, the change in the activity of the enzyme, with the change

in the concentration of the substrate, is not so great as it is at lower concentrations of the substrate. Getchell and Walton,[19] however, have shown that in the case of the peroxydase of horse-radish there is an optimum concentration of maximum activity and on further increase in the concentration of the substrate pyrogallol, the activity of the enzyme tends to decrease. Dey and Sitharaman[3] have also made similar observations with the peroxydase of Chow Chow. They have shown that the activity of the peroxydase remains constant when the concentration of the substrate is between 0.25 and 0.35 at the total volume of 13 c.c.

### Influence of temperature on the stability of the peroxydase

Most of the enzymes in solution are inactivated at a temperature above 45°C But enzymes differ in their thermostability. Some proteolytic enzymes and peroxydases can resist even 100°C, for a short period.[11] Experiments were, therefore, carried to determine the heat stability of the peroxydase under investigation.

Enzyme solutions were kept for 40 minutes at different temperatures in a thermostat and the activities were determined by taking out 10 c.c of the enzyme solution and adding to the reaction mixture, which consisted of 0.4 g. of hydroquinone, 10 c.c. of hydrogen peroxide (1.5%), 10 c.c. of buffer (PH 5.3), and the volume
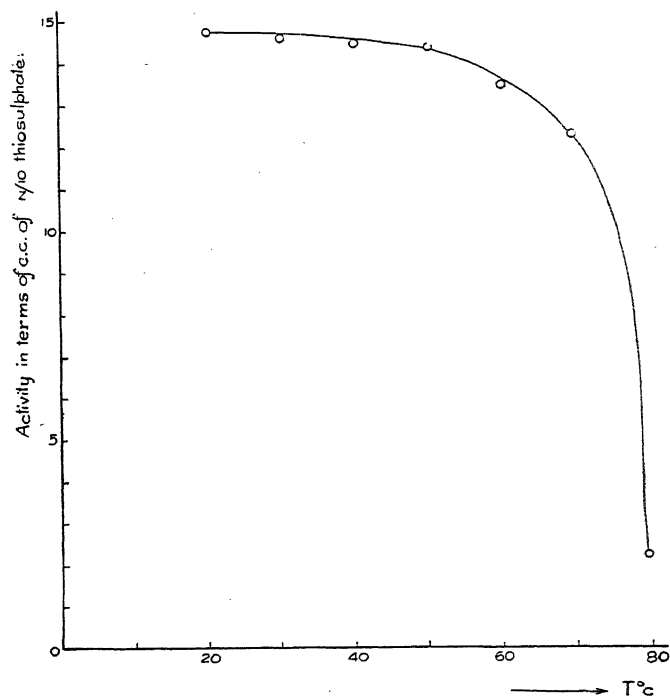


Fig 5

made up to 30 c.c. The time and temperature of the reaction were kept constant as in previous experiments. The results have been presented in Table V and Fig. V.

### Table V.

| Temperature at which the enzyme Solution was kept for 40 minutes | 20° | 30° | 40° | 50° | 60° | 70° | 80° |
|---|---|---|---|---|---|---|---|
| N/10 Thiosulphate in c.c. | 14·80 | 14·65 | 14·50 | 14·50 | 13·65 | 12·50 | 2·30 |

It may be noted that up to 50°C, the enzyme is very stable and from 60°C. the inactivation of the enzyme begins to increase considerably, as the temperatme is increased, and finally the activity of the enzyme is almost nill when it is kept at 80°C  These results indicate that the enzyme peroxydase is very stable at temperatures below 50°C.

## Stability of the peroxydase at 75°C at different hydrogen-ion concentrations.

It is well known that the reaction of the medium greatly influences the thermostability of an enzyme.  Experiments were, therefore, conducted with a view to know the range of the hydrogen-ion concentration of the medium, at which the enzyme peroxydase is most stable.

The inactivation experiments were carried out by putting 20 c.c. of the enzyme solution (original solution diluted four times) in different flasks with 20 c.c. of buffers of different PH and keeping the flasks at 75°C. for 30 minutes and finally estimating the activity.  The results are presented in Table VI.

The reaction mixture for estimating the activity constituted of 20 c.c. of Walpole's acetate buffer (PH 5·3), 0·4 g. of hydroquinone, 1 c.c. of hydrogen peroxide (15%) and 10 c.c. of the inactivated enzyme solution.  (Total volume 41 c.c.)  The reaction was carried for 15 minutes at 15°C.

### Table VI.

| PH of inactivation | | | | 6·5 | 5·3 | 4·8 | 4·0 | 3·2 |
|---|---|---|---|---|---|---|---|---|
| N/10 Thiosulphate in c.c. | | | | 5·60 | 0·25 | ... | ... | ... |

The results indicate that the enzyme is unstable at the more acid region of the medium.

Further work on the purification of the enzyme is in progress.

Our thanks are due to Prof. N. R. Dhar and Dr. S. Dutt for their kind interest in the work.

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# STUDIES ON THE EFFECT OF PHOSPHATES ON RESPIRATION OF GREEN LEAVES 1. EUGENIA JAMBOLANA, 2. ALLIUM TUBEROSUM

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## INTRODUCTION

That plants and plant-tissues give out carbon-dioxide even in absence of oxygen has long been known. And it has been accepted that the chemical reaction by which this carbon-dioxide is produced is the same as that of the alcoholic fermentation of sugar. The decomposition of respirable sugars within plant cells into alcohol and carbon-dioxide is looked upon as a vital phenomenon in as much as the early stages are common in both the anaerobic and aerobic forms of respiration, down to the formation of the immediately oxidisable basic substance, its fate and the nature of respiratory wastes being determined by the presence or absence of oxygen.

The works of Harden and Young are of special interest in connection with the alcoholic fermentation of sugars. They found that the rate of fermentation is greatly accelerated by adding boiled yeast juice to the fermenting solution. "The accelerating factor is a phosphate." Thus the alcoholic fermentation of glucose involves two definite stages, the primary stage being the production of hexose phosphates :—

$$2C_6H_{12}O_6 + 2R_2HPO_4 = 2CO_2 + 2C_2H_5OH + C_6H_{10}O_4 (PO_4R_2)_2 + H_2O$$

F. 10
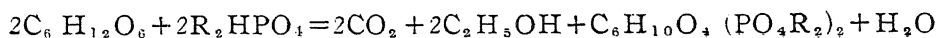
In the second stage this hexose phosphate is hydrolysed, when the free phosphate is set free to combine with glucose again, the hydrolysis being brought about by an enzyme, hexose-phosphatase :—

$$C_6H_{10}O_4 (PO_4 R_2)_2 + 2H_2O = C_6H_{12}O_6 + 2R_2HPO_4$$
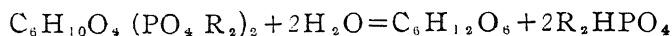
Thus phosphates which are vitally connected with alcoholic fermentation and accelerates its rate might also have a similar effect on the aerobic phase of respiration in view of what has been said before.

Iwanoff showed that phosphates exert an accelerating effect upon respiration which is related to alcoholic fermentation. Zaleski and Reinhard have found out that "these salts accelerate both the anaerobic and the oxidation phase of respiratory process."

Lyon worked on Elodea canadensis and wheat seedlings and has come to the conclusion that "phosphate increases the rate of production of $CO_2$ by anaerobic processes because of its role in the early stages of alcoholic fermentation. It effects an increase in the production of $CO_2$ by the aerobic phase of respiration through its action as a catalyst toward oxidases."

In this paper an attempt has been made to study the effects of injection of soluble neutral phosphates and phosphate-sugar solutions into leaves of tropical plants on their aerobic and anaerobic respiration and their sugar contents.

## MATERIALS AND METHOD

Leaves were the only organs selected for this work. This was so because foliage organs are best suited for a study of respiration and sugar content, these being the centre of carbohydrate formations. The materials were collected from these plants:—

(1) Eugenia jambolana, and (2) Allium tuberosum. These were selected especially because much work on the physiology of these leaves has already been done in this laboratory and also because these leaves yield themselves to injection very easily. The phosphate used throughout the work was neutral Potassium phosphate. The leaves were injected either with one per cent solution of Potassium phosphate or with a mixture of 1 gm. potassium phosphate plus 1 gm. sugar (glucose or sucrose) dissolved in 100 c.c. of distilled water. Neutral phosphate was made in this way: two 5 % solutions were prepared, one of alkaline potassium phosphate ($K_3HPO_4$) and the other of acid potassium phosphate ($KH_2PO_4$). These were titrated against each other. From the amount of solutions used the number of grams of each salt was calculated. From the result obtained it was found out how much of each salt would be contained in one gram of neutral mixture.

A vaccum pump was used for injection. For this purpose the leaves were put in a large test tube, which was filled with water or the solution as needed,

and was connected with the pump. Then, by working the pump and then releasing the pressure the leaves got injected.

For measuring respiration the following Apparatus was used.

A thermostat bath was maintained at a constant temperature, viz., 34°C-35°C. In it were kept the leaf chambers, which were moderately wide glass cylinders open at one end. The open end was fitted with a rubber stopper carrying two glass tubes bent at right angles, one was connected with the air commutator and the other with a bottle filled with strong potassium hydroxide solution to absorb carbon dioxide from the ingoing air-current. The Blackman's air commutator is so well-known that it need not be described at length. It is a device by which the respiratory current is automatically shifted on to the next Pettenkoffer tube after some fixed interval of time. This interval was three hours in the present case. The commutator was connected to Pettenkoffer tubes which in their turn were joined to large drums, filled with water, to serve as aspirators. The aspirators dropped at a uniform rate of about 1000 c.c. of water per hour, thus drawing in a slow and constant current.

The content of each Pettenkoffer tube was poured out, after the regular respiratory current had passed through it, and titrated with standard hydrochloric acid. The amount of carbon dioxide absorbed was calculated from the difference in the quantity of hydrochloric acid used to neutralise this and 25 c.c. of baryta directly.

For anaerobic current, wherever it was required, hydrogen, instead of nitrogen, was used. A Kipp's apparatus was utilized for this purpose. Pure zinc granules (free from arsenic) and pure diluted sulphuric acid (with a few crystals of pure copper sulphate) were used:—

$$Zn + H_2SO_. = Zn\ SO_4 + H_2$$
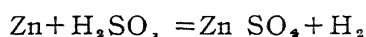
The hydrogen thus evolved was made to pass through pyrogallic acid before it entered the plant chambers.

For sugar estimations the leaves were weighed out and then boiled in water to kill the enzymes. The pieces were then thoroughly crushed with clean sand, and then the paste was thoroughly mixed with the same water which was used to kill the enzymes. The whole mass was then pressed through a thin cloth and the liquid thus obtained was filtered by means of a Buchner Funnel. Lead acetate was added to the filtrate for precipitating tannin. The extra amount of lead in the filtrate was got rid of by repeatedly passing hydrogen sulphide. The surplus amount of hydrogen sulphide was boiled off. The volume of solution was measured and the amount of sugar was estimated by titrating against Pavy's solution.

For the estimation of the disaccharides a known volume of the leaf extract was previously boiled with 1 c.c. of conc. hydrochloric acid and then neutralised with sodium bicarbonate. The difference between the results obtained with

hydrolised and unhydrolised leaf-extracts multiplied by '95 gives the amount of disaccharides.

## RESULTS AND GENERAL DISCUSSION

I. *The comparison of $CO_2$ values obtained in air.*—For the purpose of general discussion it would be better to take up the curves in air and in hydrogen separately. Fig. 1 shows the respiratory curves of Eugenia jambolana in air
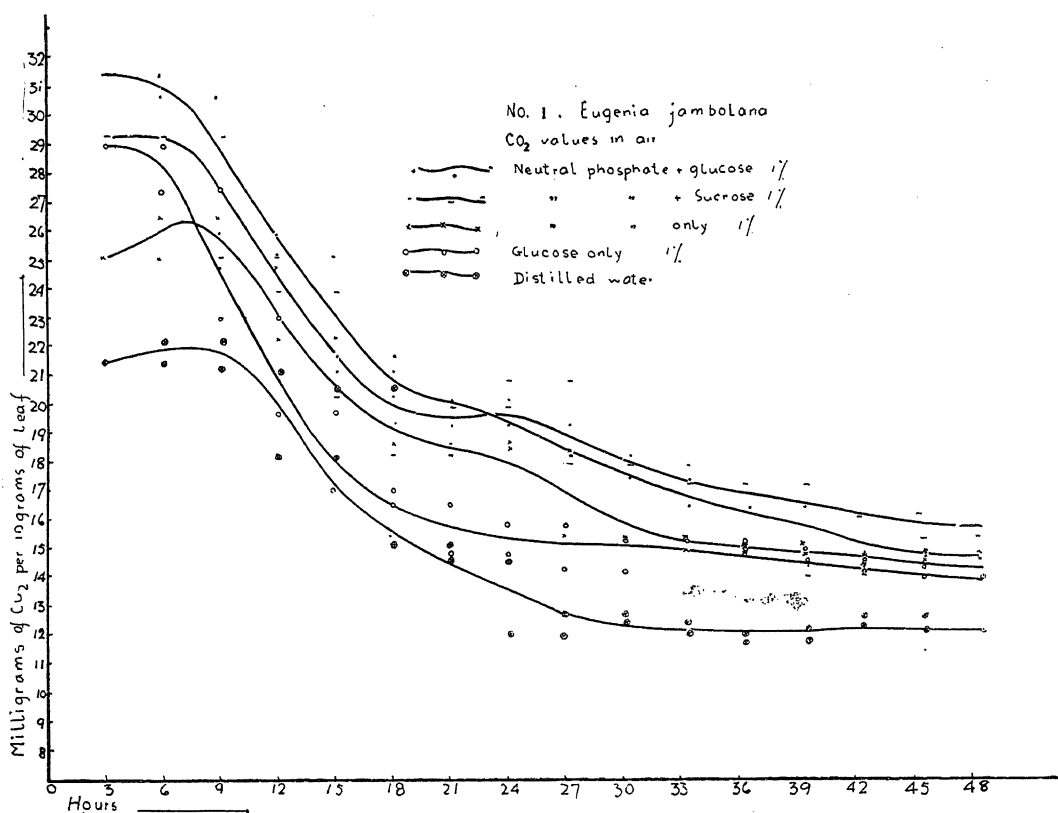


Fig. 1

An Examination of this figure will reveal the fact that the respiration of the water-injected leaves is lowest of all, above it comes that of the glucose-injected ones, then comes the phosphate-line, and then above all are the phosphate-sugar curves.

A similar figure (Fig. 2) in the case of Allium leaves reveals the same facts, starting from the lowest to the highest the various curves are in the following
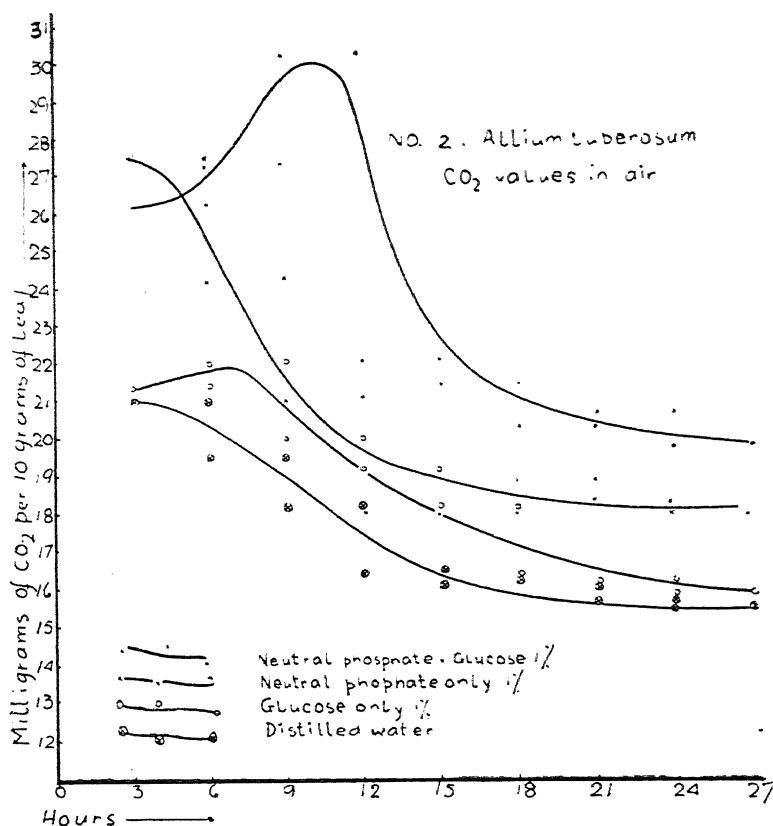


Fig. 2

order—water-line, glucose-line, phosphate-line and finally the phosphate-glucose line.

It would be profitable to find out some relation between the respiratory intensities of the variously injected leaves so that they may directly comparable with reference to same standard. For this purpose the $CO_2$ value of the water-injected leaves has been taken as a standard and the respiratory values of the differently-treated leaves have been referred to it. The following table (No. 1) gives the approximate ratio obtained in this way.

*Table 1*

| Treatment of leaves. | Time | Mgs $CO_2$ given out. | Ratio (approximate). |
|---|---|---|---|
| Eugenia jambolana | ... | ... | ... |
| Glucose injected<br>Water injected | 45 hours | 265·0<br>228·7 | 1·15 |
| Phosphate injected<br>Water injected | 45 hours | 277·8<br>228·7 | 1·22 |
| Phosphate + glucose injected<br>Water injected | 45 hours | 304·1<br>228·7 | 1·33 |
| Phosphate + sucrose injected<br>Water injected | 45 hours | 304·1<br>228·7 | 1·32 |
| Allium tuberosum | ... | ... | ... |
| Glucose injected<br>Water injected | 24 hours | 149·0<br>137·9 | 1·08 |
| Phosphate injected<br>Water injected | 24 hours | 163·8<br>137·9 | 1·2 |
| Phosphate + glucose injected<br>Water injected | 24 hours | 187·3<br>137·9 | 1·36 |

It will be seen from above table that the ratio between the $CO_2$ output of phosphate-sugar injected leaves to that of water-injected ones is greater than the ratio obtained in the cases of others.

II. *The comparison of $CO_2$ values obtained anaerobically.* — When the leaves, similarly injected as the above are subjected to hydrogen-treatment for some time, the $CO_2$ values, thus obtained anaerobically, stand in the same gradation as that obtained in air. Figs. 3 (Eugenia jambolana) and 4 (Allium tuberosum) will make it clear. It will be seen that the $CO_2$ output of the water-injected leaves is lowest of all, higher than this comes that of the glucose-injected ones, the phosphate-line follows next and highest is the phosphate-sugar-line.

The following table (No. 2) gives the relation of the $CO_2$ values of the leaves treated differently with reference to the $CO_2$ output in the case of water-injected leaves, in anaerobic treatment.

NO. 4   Allium tuberosum
Anaerobic $CO_2$ values

Neutral phosphate + Glucose 1%
"        "      Glucose only 1%
Glucose only 1%
Distilled water

Milligrams of $CO_2$ per 10 grams of Leaf

Hours

Fig. 4



NO. 3.   Eugenia jambolana
Anaerobic $CO_2$ values

Neutra phosphate + glucose 1%
"        "       sucrose 1%
"        "       only 1%
Glucose only 1%
Distilled water

Milligrams of $CO_2$ per 10 grams of Leaf
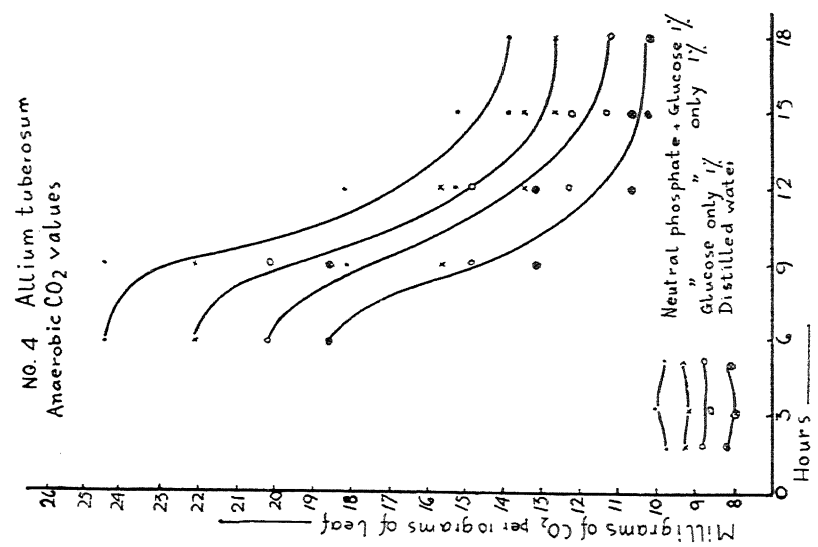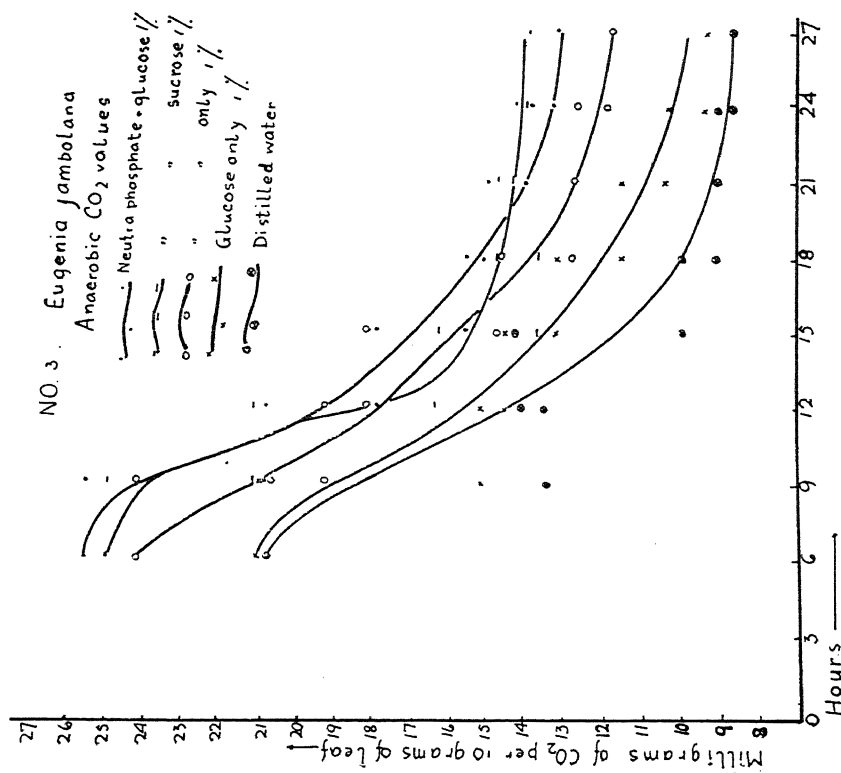
Hours

Fig. 3

## Table 2

| Treatment of leaves. | Time. | Mgs. $CO_2$ given out. | Ratio (approximate). |
|---|---|---|---|
| Eugenia jambolana ... | ... | ... | ... |
| Glucose injected ... ... | | 95·7 | |
| Water injected ... ... | 21 hours | 84·3 | 1·13 |
| Phosphate injected ... | | 113·1 | |
| Water injected ... ... | 21 hours | 84·3 | 1·34 |
| Phosphate+glucose injected .. | | 121·2 | |
| Water injected ... ... | 21 hours | 84·3 | 1·44 |
| Phosphate+sucrose injected ... | | 118·2 | |
| Water injected ... ... | 21 hours | 84·3 | 1·4 |
| Allium tuberosum ... ... | ... | ... | ... |
| Glucose injected ... .. | | 58·6 | |
| Water injected ... ... | 12 hours | 52·3 | 1·1 |
| Phosphate injected ... ... | | 63·8 | |
| Water injected ... ... | 12 hours | 52·3 | 1·22 |
| Phosphate+glucose injected ... | | 71·7 | |
| Water injected ... ... | 12 hours | 52·3 | 1·37 |

The ratio between the $CO_2$ output phosphate-sugar injected leaves and that of water-injected leaves is thus seen to be the greatest. Below this comes the ratio between the $CO_2$ values of phosphate injected and water injected leaves and finally the lowest of all is the ratio of glucose and water-injected leaves. If a comparison is made between these figures and those obtained from $CO_2$ values in air (given in table No. 1) it will be seen that they are almost the same in both the cases, those of Eugenia jambolana being very slightly higher in case of anaerobic treatment. But on the whole the results obtained here are similar to those obtained in air.

III. *Comparative study of the "after-effect".* — Temporary anaerobiosis is generally accompanied by a rise of the $CO_2$ value, when aerobic conditions are restored. Here also when the leaves, respiring in hydrogen, were brought back to air a huge extra amount of $CO_2$ was produced before the $CO_2$ output became steady once again. The following figure (No. 5) offers a comparative study of the after-effects of the variously treated leaves in the case of Eugenia jambolana. It is evident from the figure that the water-injected leaves have the lowest after-effect; above this is that of glucose-injected leaves. The highest after-effects are those given by Phosphate-sugar-injected leaves and below this is the phosphate hump. In the following table (No. 3) are given the ratio

between the total $CO_2$ output of leaves, variously treated, with that of water-injected ones, after the restoration of air current:
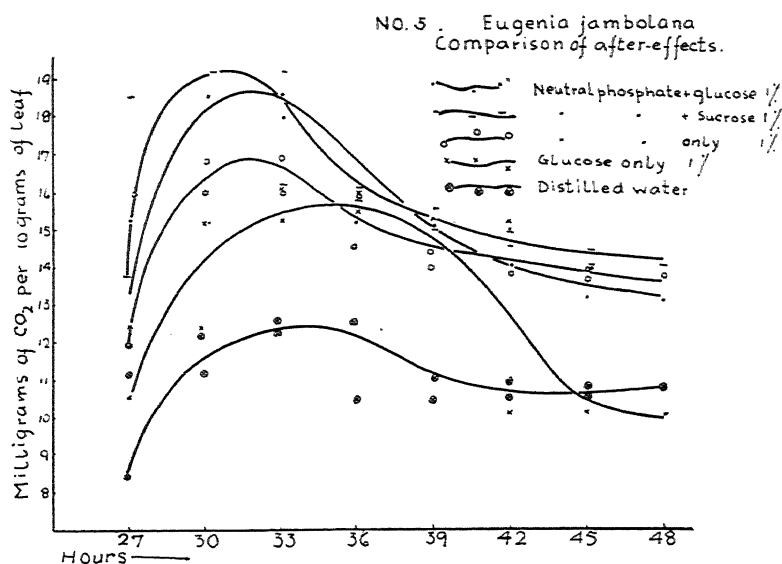


Fig. 5

Thus the Phosphate-sugar injected leaves give the highest ratio, below this come the phosphate-injected leaves, and lowest of all the sugar-injected ones. A comparison of these figures with those calculated from the $CO_2$ values of leaves respiring in air throughout, will correspond that they reveal with each other, although the ratio in the case of after-effects are a little higher.

Table 3

| Treatment of leaves. | Time. | Mgs. $CO_2$ given out. | Ratio (approximate). |
|---|---|---|---|
| Glucose injected ... ... | | 94·9 | |
| Water injected ... ... | 21 hours | 78·6 | 1·2 |
| Phosphate injected ... ... | | 104·8 | |
| Water injected ... ... | 21 hours | 78·6 | 1·33 |
| Phosphate + glucose injected ... | | 107·6 | |
| Water injected ... ... | 21 hours | 78·6 | 1·4 |
| Phosphate + sucrose injected ... | | 113·7 | |
| Water injected ... ... | 21 hours | 78·6 | 1·44 |

But the same condition of things do not exactly obtain in the case of Allium tuberosum leaves as will be clear from the following table (No. 4). Here the last two figures are the same, but in the case of aerobic conditions, dealt with previously, the ratio between the $CO_2$ value of phosphate-glucose-injected leaves

F. 11

*Table 4*

| Treatment of leaves. | Time. | Mgs. $CO_2$ given out. | Ratio (approximate). |
|---|---|---|---|
| Glucose injected ... .. <br> Water injected ... ... | 12 hours | 46 0 <br> 44·9 | 1·02 |
| Phosphate injected ... ... <br> Water injected ... | 12 hours | 52·6 <br> 44·9 | 1·17 |
| Phosphate+glucose ... <br> Water injected ... ... | 12 hours | 52·4 <br> 44·9 | 1·17 |

and that of water-injected leaves was higher. Such a coincidence of figures as has been obtained here, may be taken as accidental.

IV. *The effect on sugar-content in the case of respiration in air.*—Sugar estimations were done in many cases before and after the experiments. From these the amount of sugar utilized during respiration was found out. It would be profitable to compare the sugar values of leaves that were given phosphate, either alone or in a mixture, with those that were not given phosphate at all. This is shown in the following table (No. 5).

*Table 5*

| Treatment of leaves. | Mgs. Monosaccharides consumed per 10 grams. | Mgs. Disaccharides consumed per 10 grams. |
|---|---|---|
| Eugenia jambolana ... .. | | |
| Exp. 1. { A. Phosphate only ... ... | 79 | 31 |
| Exp. 1. { B. Water only ... .... | 65 | 26 |
| Exp. 3. { A. Phosphate+glucose ... | 69 | 34 |
| Exp. 3. { B. Glucose only .. ... | 59 | 29 |
| Allium tuberosum ... ... | | |
| Exp. 7. { A. Phosphate only ... ... | 80 | 30 |
| Exp. 7. { B. Water only ... .. | 73 | 24 |
| Exp. 9. { A. Phosphate+glucose ... | 85 | 21 |
| Exp. 9. { B. Glucose only ... ... | 72 | 19 |

Thus it will at once be evident that more sugar, both monosaccharides and disaccharides, has been consumed, during respiration, in those leaves in which either phosphate or a mixture of phosphate and glucose has been injected.

A similar consumption of more sugar by the leaves injected with phosphate is also manifested in experiments in which they were treated anaerobically, as will be observed from the following table (No. 6).

*Table 6*

| Treatment of leaves. | | Mgs. Monosaccharides consumed per 10 grams. | Mgs. Disaccharides consumed per 10 grams. |
|---|---|---|---|
| Eugenia jambolana | | | |
| Exp. 2. | A. Phosphate only ... ... | 91 | 41 |
| | B. Water only ... ... | 84 | 34 |
| Exp. 4. | A. Phosphate+glucose ... | 72 | 35 |
| | B. Glucose only ... ... | 58 | 31·1 |
| Allium tuberosum ... ... ... | | | |
| Exp. 8. | A. Phosphate only ... ... | 85 | 27 |
| | B. Water only ... ... | 79 | 22 |
| Exp. 10 | A. Phosphate+glucose ... | 93 | 32 |
| | B. Glucose only ... .. | 86 | 30 |

V. *Effect of phosphate on starved leaves.*—This greater consumption of sugar in the phosphate-injected leaves is compatible with their higher respiration level. A glance at the figures (1 and 2) will bring out the fact that the differences between the various curves tend to decrease towards the latter hours of the experiment. Thus the initial differences between the curves are far greater than the final differences. This may be taken to mean that the differences tend to minimise as the store of respirable matter becomes more and more exhausted, *i.e.*, the decrease in the sugar content of the leaves, possibly, modifies the effect of the phosphate on their respiration. Of special interest in this connection is the following figure. Here the leaves (of Eugenia jambolana) were injected with phosphate after 21 hours starvation, by which time their sugar content decreased appreciably

and therefore, its subsequent respiratory rate did not rise much above that of the control. The following table (No. 7) brings out its contrast with the results
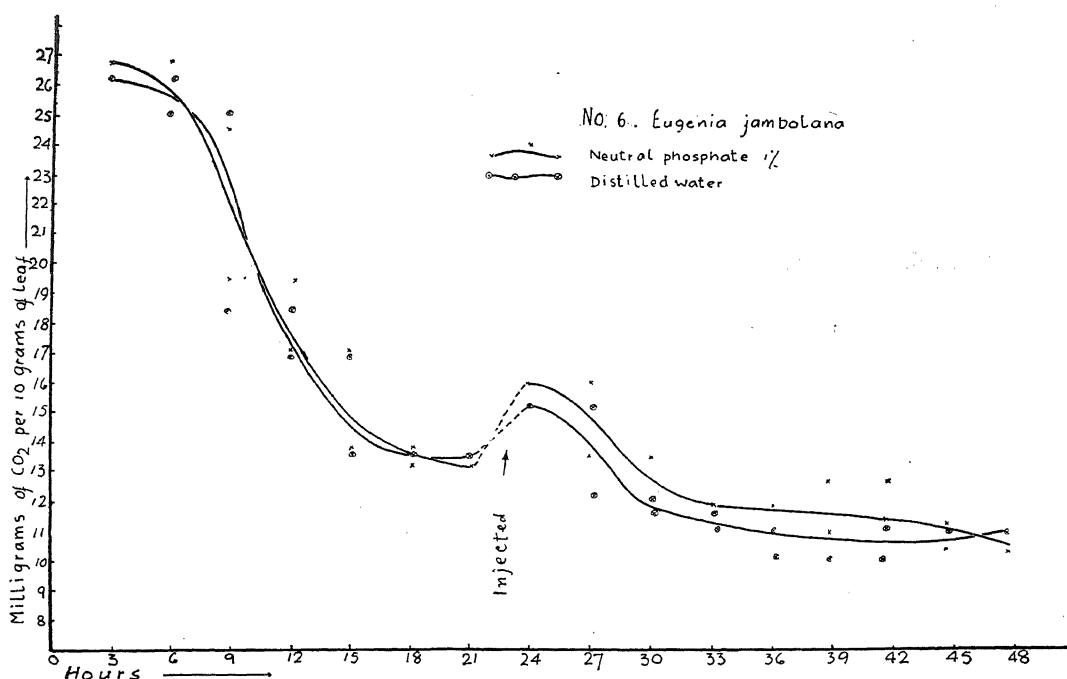


Fig. 6

given in Fig. 1, where the leaves were injected with phosphate from the very beginning.

Table 7

| Eugenia jambolana treatment of leaves. | | Mgs. $CO_2$ per 10 grams. of leaf. | Diff. between A and B. | Time. |
|---|---|---|---|---|
| Results from Fig. 1 | A. Phosphate only ... | 174·5 | 29·6 Mgs. | First 24 hours. |
| | B. Water only ... | 144·9 | | |
| Results from Fig. 6 | A. Phosphate only ... | 100·1 | 8·6 Mgs. | Last 24 hours. |
| | B. Water only ... | 91·5 | | |

It may be said that the diminution of the difference between the $CO_2$ values of the phosphate-injected and water-injected leaves is primarily due either to the depletion of phosphate in some way or somehow to its removal from the metabolic centre. The results just dealt with, (table 7) seem to go against such a suggestion, as injection of starved leaves with phosphate did not raise the $CO_2$

output much above that of the water-injected ones. So that when sugar is less and phosphate is retained at the original value, the effect of the latter on respiration is almost negligible.

VI. *The phosphate sugar effect.*—The above considerations seem to indicate that phosphate by itself would not, very possibly, affect respiration in any marked degree, if respirable sugars are wanting, or are present in small quantities. Such a suggestion is supported by the fact that phosphate-sugar mixtures accelerate respiration very much more than either of them singly and that phosphates quicken respiratory rate more in the beginning, when the leaves are more sugary, than towards the end when sugar content is greatly diminished due to continuous starvation. Such a combined effect of sugar and phosphate seems to be possible only when the latter is mixed with anhexose sugar; with a disaccharide such an acceleration would probably be delayed till it is hydrolysed to monosaccharides.

VII. *The possible mechanism of phosphate reaction.*—The possible connection of phosphates with alcoholic fermentation has been brought out by the investigations of Harden and Young, as being the formation of hexose-phosphate and its consequent hydrolysis. Hence the addition of soluble phosphates to a fermenting liquid accelerates the rate of fermentation. It therefore seems probable that the acceleration of the rate of anaerobic $CO_2$ output of leaves injected with phosphate is to be traced to the increased formation of hexose-phosphate according to the reaction :—

$$2C_6 H_{12} O_6 + 2R_2HPO_4 = 2CO_2 + 2C_2 H_5 OH + C_6 H_{10} O_4 (R_2PO_4)_2 + H_2O$$
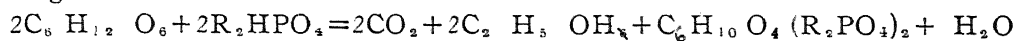
This view is all the more strengthened by the fact that acceleration of $CO_2$ production is the greatest in the case of leaves injected with a mixture of phosphate and glucose.

Lyon while accepting the above view in the case of increased anaerobic production of $CO_2$ by phosphate, is of opinion that in the aerobic phase, the accelaration of $CO_2$ output is due to their "action as a promoter catalyst toward oxidases."

Against this there is the widely accepted theory that aerobic and anaerobic respirations have common initial stages and whether, after this, the ultimate respiratory material will break into water and $CO_2$ or alcohol and $CO_2$ is determined by the presence or absence of oxygen. The names of Kostychev and Palladin among many others is specially associated with such a theory. It implies that anything which affects the preliminary stages of anaerobiosis in one way will similarly affect the aerobic phase as well since both have a common beginning. Moreover, if phosphates act toward oxidases as promoter catalysts, all the available sugar, however small in quantity, ought to be oxidised at an accelerated rate, and consequently the $CO_2$ output ought to be maintained at a higher level so long as oxidasable carbohydrates are available. But such a level of $CO_2$ was not maintained in the experiments described above, for the final $CO_2$ value was far lower than

what was initially.    Moreover the various ratios obtained from aerobic $CO_2$ values correspond with those obtained anaerbically and even with those obtained form the extra amount of $CO_2$ output of the after-effects. This common ratio perhaps points out that the reactions responsible for the increased $CO_2$ output of phosphate-injected leaves, may be the same both in aerobic and anaerobic forms of respiration.    It may be however that Lyon's explanation is not totally exclusive of the possibilities of other reactions as well.    Probably the accelaration of $CO_2$ production should be traced to more causes than one.    And the possibility of such an increase through a combination of simple sugars and phosphate at once commends itself.

### SUMMARY

Experiments have been carried out on leaves Eugenia jambolana and Allium tuberosum to study the effects of phosphates on respiration both in aerobic and anaerobic conditions.

It has been found out the acceleration of $CO_2$ output is the greatest when the leaves are injected with a mixture of phosphate and glucose; injection with phosphate alone causes more $CO_2$ production than that with sugar alone; and both phosphate and sugar individually have a greater effect than injection with distilled water.   This holds good both in the aerobic and anaerobic production of $CO_2$

The acceleration is highest in the beginning of experiments and decreases with time.

Injection of starved leaves with phosphate causes very little change in $CO_2$ output.

Sugar-estimations reveal the fact that phosphate-injected leaves utilize more sugar than non-phosphate ones.

It has been suggested that phosphates have very little effect on respiration when very little sugar is available for respiratory purposes.

The suggestion has been put forward that the phosphate acts through the intermediate stage of hexose-phosphate.

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# ON AN ECHINOSTOME CERCARIA—CERCARIA PALUSTRIS—WITH NOTES ON ITS LIFE-HISTORY

## By R C. CHATTERJI

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During the months of July to October in Allahabad one of the common Indian Snails—*Indio-planorbis exustus* (Deshayes)—is heavily infected with an Echinostome Cercaria—*Cercaria palustris* n. sp. The collar spines are very inconspicuous and often escape notice unless examined under an oil immersion lens Faruqui (1930, 1205) has recently described—*Cercaria mehrai*—a cercaria completely spineless, but very similar in appearance to *C. palustris*, collected from the same host from Handia, a village about 25 miles east of Allahabad.

The author's personal examination of a large number of snails from Handia during the month of September has convinced him that *C. palustris*, so commonly found at Allahabad, is of common occurrence at Handia in that part of the year, and that unless a very high magnification is used, it is practically impossible to see the collar-spines which are present in it. The rate of infection was much higher than that of *C. mehrai* during the middle of September: out of 168 snails examined 103 were found infected. The rate, however, gradually decreased until in December and January when it was practically the same as that of *C. mehrai*. Faruqui has not mentioned any definite period when his observations were made and the writer is therefore unable to compare his rate of infection with the present rate. *C. palustris* presents certain striking similarities with *C. mehrai*, but at the same time it shows certain important features, which have either been overlooked by Faruqui in *C. mehrai*, or are entirely absent in it, as his description shows. I have examined a large number of snails from the same locality where Faruqui got his material from, but I have never come across a single specimen of *C. mehrai*. This fact confirms my suspicion that the latter species may be the same form as that described by me and that Faruqui may have failed to observe such important features as the collar spines and the intestinal caeca which are hardly visible under ordinary magnifications. But, in view of these important discrepancies in the description of *C. mehrai*, and my form, I do not think it proper to include my species under the same name and feel justified, under the circumstances, to create a new species for it, though, it is quite possible, as I have already pointed out, that further work may reveal the necessity of bringing both these species together as synonyms under one species.

The author wishes here to express his sincere thanks to Dr. H. R. Mehra for his help and guidance and to Prof. D. R. Bhattacharya for the provision of facilities for work in the department. Acknowledgments are also due to Prof. F. J. Meggitt for his suggestions and the use of his personal library.

## CERCARIA

The cercariae emerge from the body of the snail in hordes and wriggle actively in water in an undulating manner by movements of both the body and tail. While swimming the cercaria curves its body ventrally, occasionally sinking to the bottom and there crawling by alternately contracting and expanding its body and gripping tightly the surface of the object with the suckers. Due to extreme contraction and expansion the size varies considerably as shown by the following table : —

|       |                  |     |     | Contracted. | Expanded. |
|-------|------------------|-----|-----|-------------|-----------|
| Body: | Length           | ... | ... | 0˙231*      | 0˙456     |
|       | Maximum breadth  |     | ... | 0˙185       | 0˙072     |
| Tail: | Length           | ·   | ... | 0˙252       | 0˙483     |
|       | Maximum breadth  | ·   | ... | 0˙063       | 0˙045     |

The following measurements are of a semi-contracted specimen :—

| Dimensions of ventral sucker | ... | ... | 0˙057 × 0˙05 |
|------------------------------|-----|-----|--------------|
| Dimensions of Oral sucker    | ... | ... | 0˙045 × 0˙04 |
| Dimensions of Pharynx        | ... | ... | 0˙023 × 0˙019 |

Changes in size of the body also affect its general outline. At maximum expansion the two lateral margins are more or less parallel, pear-shaped in a semi-contracted stage, and more or less rounded in fully contracted condition. Inside the cuticle is a granular layer, probably representing the *epidermis*, apparently absent from the tail. Beneath the epidermis are numerous, more or less spherical, cystogenous cells of refractile appearance and filled with "rod-lets" arranged in parallel rows. These cells are more numerous in the periphery than in the centre and cover other organs of the body. Their number is much larger in older specimens, which, on account of their presence make the animal less transparent and more difficult to study. Both the body and the tail are provided with longitudinal and transverse muscles, which are specially well-developed and, therefore, more active in the region between the suckers than in any other part of the body, so that the great changes in the dimensions of the body due to the contraction and expansion of these muscles effect greatly the preacetabular region.

The tail, when extended, is a little longer than the body, but during semi-contracted condition of the cercaria it is shorter than the body length. It is attached on the ventral aspect of the body and except its terminal portion it is less contractile

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* All measurements are in millimetres,

than the body and is not easily detached even in specimens, that have had a free active existence of over eight hours. Beneath the cuticle of the tail lies a layer of strong circular muscle fibres, followed more internally by a layer of longitudinal fibres. More internally the tail is composed of parenchymatous tissue, through the centre of which runs the main excretory caudal canal. The terminal end of the tail is very contractile and the cuticle surrounding it very thin.

The ventral sucker is slightly shorter antero-posteriorly than in its transverse diameter and is situated nearly in the posterior one-third of the body. The oral sucker lies anteriorly close to the cutis and, like the ventral sucker, is shorter antero-posteriorly. On the surface of the body close to the posterior margin of the oral sucker are collar-spines, only visible under high magnifications. Owing to the minuteness of the spines, and also to the overcrowding of the cystogenous cells, it is difficult to count their exact number. The number was, however, found to be twenty-nine or a few less, as counted in a few specimens, while occasionally in the encysted stage as many as forty spines were observed to be present. They are arranged in two rows, one alternately above the other, in a dorsally incomplete circle.

The mouth is subterminal, leading into the cavity of the oral sucker and followed by a long prepharynx. The pharynx is muscular. The oesophagus is a little thicker and longer than the prepharynx and runs between two rows of gland cells lying in the centre of the body. Very close to the anterior margin of the acetabulum, it bifurcates into two long caeca, which curve first outwards, then inwards, to end blindly at the hinder end of the excretory bladder. The caeca are difficult to see except when filled with granular food particles or when there is a slight congestion of the cystogenous cells. The six salivary gland cells lie in two longitudinal rows, one on each side of the oesophagus. Each cell is provided with lobed margins, a well-developed nucleus in the centre, and granular protoplasm around the periphery. The ducts are very inconspicuous and could not be observed. Near the anterior margin of the oral sucker on the both sides of the median line, certain tubules were, however, seen, which I presume are continuations of the salivary ducts. Faruqui (1930) has failed to observe any salivary gland cell in *C. mehrai*, but on the other hand finds a mass of hexagonal cells, varying in number from six to eight, very similar in position to the salivary gland cells of *C. palustris*, and which he considers as cells of the vagina.

The excretory bladder is thick-walled and situated at the extreme hinder end of the body. Its shape differs according to the extent of contraction and expansion: during contraction it assumes more or less a spherical appearance. The primary excretory tubes are thinwalled and narrow. They arise from the anterior aspect of the bladder through a common orifice and take a wavy course outwards and forwards. At the level of the anterior part of the acetabulum, the tube widens to accommodate a series of large six or seven spherical or oval excretory granules of

F. 12

the usual refractile appearance. This dilated part of the main duct occupies laterally a great part of the body length and becomes constricted into a narrow tube at about the region of the pharynx, when it bends upwards and downwards in the form of a loop, running dorsally in close apposition to the dilated part as far as the level of the acetabulum. From there it is deflected laterally and continues back to the posterior end of the body. At the side of the bladder the tube turns forwards to traverse for the third time the entire length of the body (Fig. 2). In the body twelve pairs of flame cells could be seen, but it is possible that the number may be larger. Of these five pairs are pre-acetabular, one at the level of the acetabulum and the remaining six pairs post-acetabular in position. The first pair lies close against the posterior margin of the oral sucker, the second and the third laterally in the body, one anterior and the other posterior to the excretory loop; the fourth near the third excretory granule; the fifth close to the anterior margin of the acetabulum; the sixth at level with the acetabulum; the seventh posterior to the acetabulum, and the remaining five pairs near and outside the bladder. The flame cells are absent from the tail, in which the excretory system is represented only by a median duct arising from the posterior margin of the excretory vesicle and opening to the exterior to the left side close in front of the abrupt ending of the tail. The genital organs are represented by a mass of small rounded cells in the post-acetabular region, which on account of their size appear to be cells of the ovary: in some cercariæ they develop into a compact mass of larger cells with prominent nuclei and granular cytoplasm. Some cercariæ of the same species obtained from Rangoon showed in addition a few groups of spherical cells near the anterior margin of the ventral sucker.

## Redia

Development of the cercariæ takes place in rediæ. These are found closely packed in the liver mass of the host from which they are easily detached. They generally occur in large numbers, sometimes exceeding two hundered fifty in number. Freshly detached rediæ are orange-brown in colour, due to the presence of particles of the liver in which they lie embedded. Rediæ obtained from a single host are of various stages and sizes having guts in different proportions to the body length. A well-developed redia measures approximately 2·66 in length whereas a young one measures only 0·457. The mouth is terminal followed by a well-developed protrusible pharynx, measuring 0·042 × 0·036. The pharynx is followed by a deep brown rhabdocæle gut, the colour being imparted by the food particles. A little distance behind the pharynx lies the collar, a band-like thickening around the body, slightly projecting from it. The collar is inconspicuous in most of the rediæ but it is well-developed in the young forms. Posterior to the collar lies a depression in the body wall, in the centre of which there is a crescentic orifice, the 'birth-pore'. In the hinder part of the body the redia is provided with

a pair of locomotor processes with which it slowly moves on. Cercariæ are densely packed in the body cavity of a mature redia and emerge out of the birth-pore by either their anterior or posterior ends.

## METACERCARIA.

The cysts of *C. palustris* were commonly found in the tissues of *Indo-planoribis exustus* (Deshayes) but occasionally such cysts were also obtained form *Limnea acuminata.* The number of cysts varies in different snails, ranging from approximately a dozen to nearly four hundred. The author's personal observations have led him to believe that the cercariæ emerge from the tissues of their hosts and re-enter fresh snails to encyst, failing which they die and sink. This is in opposition to the belief held by Johnson (1920), who holds that this procedure necessitates a waste of individuals without any apparent benefit.

A well-developed cyst measures as follows:—

| | | | | | |
|---|---|---|---|---|---|
| Cyst: | Length | ... | ... | ... | 0˙153 |
| | Breadth | ... | | ... | 0˙126 |
| Oral sucker: | Length | ... | ... | ... | 0˙028 |
| | Breadth | ... | ... | ... | 0˙04 |
| Ventral sucker: | Length | ... | ... | ... | 0˙03 |
| | Breadth | ... | ... | ... | 0˙045 |
| Oesophagus: | Length | ... | ... | .. | 0˙03 |
| Intestinal caeca: | Breadth | ... | ... | ... | 0˙01 |

The cyst is covered by a chitinous wall, the thickness of which differs in different cases, the minimum thickness being 0˙004 and the maximum 0˙007. The inconspicuous collar spines of the cercariæ are very prominent in the cyst. Their correct number is very difficult to determine but on the average it appears to be twenty-nine. In a few cases as many as forty spines have been noticed. It is possible that all the collar spines may not be visible due to retraction of this part of the body in the living cyst and this probably accounts for the great variation in number of collar spines in different cysts. The cyst is transparent and refractile. It can be separated from its wall by exerting a slight pressure over it under a cover-slip. The mouth in the encysted cercaria is terminal opening into the cavity of the oral sucker, followed by a prepharynx. The pharynx is muscular and followed by a well-developed intestine, which bifurcates in front of the acetabulm to continue into two caeca ending blindly near the hinder end of the excretory bladder. The gut is quite prominent and is filled with food granules in its entire course. The excretory system in the cyst is very similar to that of the cercariæ, but the excretory loop is filled with a number of excretory granules.

## DISCUSSION

*Cercaria palustris* closely resembles *Cercaria mehrai* but for three distinctive features, *i.e.*, the presence of somewhat inconspicuous collar spines, bifurcation of the æsophagus into two narrow caeca, and the presence of gland cells. It appears, therefore, necessary to treat it as a new species. The resemblance between the two species is marked in the structure of the tail, suckers and the gut (excluding the caeca which are reported to be absent in *C. mehrai*). The cystogenous cells are also similar though more or less spherical instead of 'rectangular' or 'irregular geometrical shape' as in the latter species. The shape of the excretory bladder and the course of the excretory ducts are almost similar with only minor differences. The flame cells also correspond more or less in number and position, there being twelve pairs in the present species and ten in *C. mehrai*. Owing to the highly contractile nature of the cercariæ no special importance can be attached to the difference in size of the body and tail.

According to the existing system of classification of the Echinostome Cercariæ it is extremely difficult to assign this cercaria to any particular group. It resembles and differs all the groups in great features except the 'Megalura' created by Cort (1915) from which it can be sharply separated on account of profound differences. The characters, which *C. palustris* has in common with the '*Echinotoides*,' '*Coronata*' and '*Echinata*' groups are given in tables 1, 3, and 5 respectively, while the differences between them are given in tables 2, 4, and 6.

Table 1.—Resemblances with the 'Echinotoides' group.

(*a*)   Collar spines arranged in double rows.

(*b*)   Cystogenous cells with parallel rods of protoplasm.

(*c*)   Extreme tip of the tail pointed to a conical process and capable of independent contraction and expansion.

(*d*)   Thin cuticle surrounding the terminal end of the tail.

(*e*)   Alimentary system complete with distinct lumen.

(*f*)   A few salivary gland cells with granular protoplasm.

Table 2.—Differences with the 'Echinotoides' group.

(*a*)   Absence of fin-fold in the tail.

(*b*)   Ventral sucker longer in transverse diameter.

(*c*)   The course of the excretory tubes different.

Table 3.—Features of resemblance with the 'Coronata' group.

(*a*)   Double rows of spines in the collar of approximately equal size.

(*b*)   Cystogenous cells with parallel rods of protoplasm.

(*c*)   No fin-fold on the tail.

Table 4.—Differences with the 'Coronata' group.

(*a*)   Difference in the course of the excretory tubes.

(*b*)   Variation in the proportionate length of the gut of rediæ with body length.

Table 5.—Resemblances with the 'Echinata' group.

    (a)  Double rows of spines in the collar.

    (b)  No fin-fold on the tail.

    (c)  Course of the excretory tubes identical.

    (d)  Variation in the length of gut in different rediæ

    (e)  Encystment of the cercariæ within the tissues of mollusc host.

Table 6.—Differences with the 'Echinata' group.

    (a)  Absence of spines on the body.

    (b)  Cystogenous cells not with granular contents.

    (c)  Salivary glands not composed of numerous small pyriform cells.

From the foregoing comparison it may be seen that the existing classification of Echinostome cercariæ is unsatisfactory. *Cercaria palustris* appears to be a transitional form between the various groups. If, as is held by Cort, Faust, Sewell and others, the excretory system be considered the sole, or the chief character of systematic importance, then *Cercaria palustris* should be placed in the 'Echinata' group. This, however, involves a complete unimportance of all other characters, which is liable to result in an unnatural system of classification.

## EXPLANATION OF PLATES.

Fig. 1. *Cercaria palustris* n. sp.—ventral aspect (Semi-diagrammatic).

Fig 2. *Cercaria palustris* n sp.—showing the excretory system (diagrammatic).

Fig. 3. Redia of *Cercaria palustris* n. sp.—ventral aspect (camera lucida drawing).

Fig. 4. Cyst of *Cercaria palustris* n. sp.—ventral aspect (camera lucida drawing).

Fig. 5. Cysts of *Cercaria palustris* n. sp.—(microphotograph: under low power).

Fig. 6. Cyst of *Cercaria palustris* n. sp.—(microphotograph, under oil immersion lens).

## LETTERING TO FIGS. 1—6.

C. cyst, cer. cercaria, cet. caudal excretory tube, cr. collar region, cs· collar spines, e. g. excretory granule, ep excretory pore, es. oesophagus, ev. excretory vesicle, fc flame cell, glc. cystogenous cell, ie. intestinal cæcum, lp. locomotory process, met. mainlateral excretory tube, os. oral sucker, ph. pharynx, pph. prepharynx, rd. rhabdocœle gut, sg. salivary gland cell, vs. ventral sucker or acetabulum.

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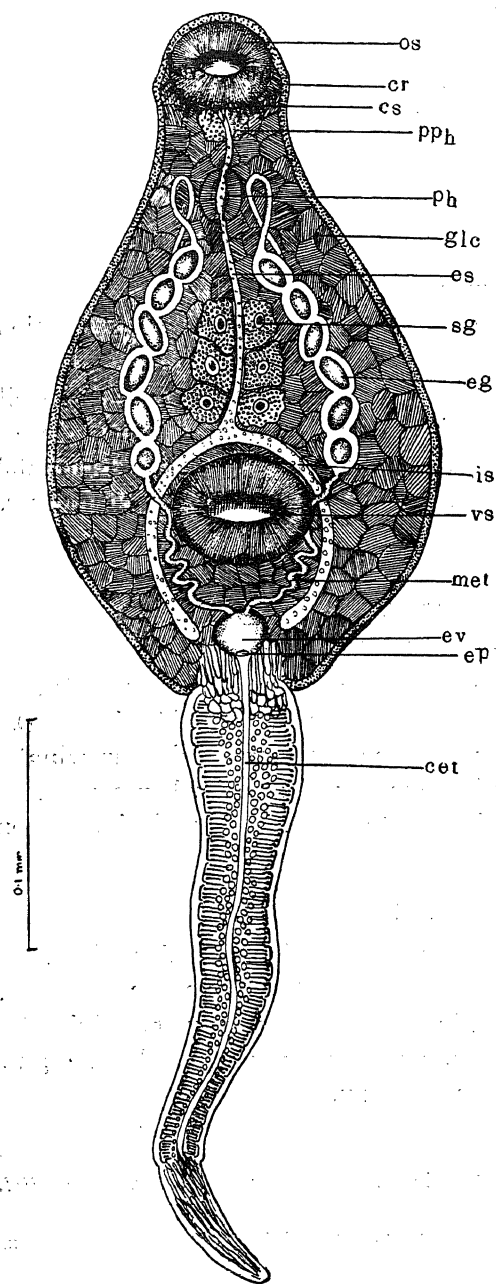
Fig. 1.—*Cercaria palustris* n. sp.—Ventral aspect.
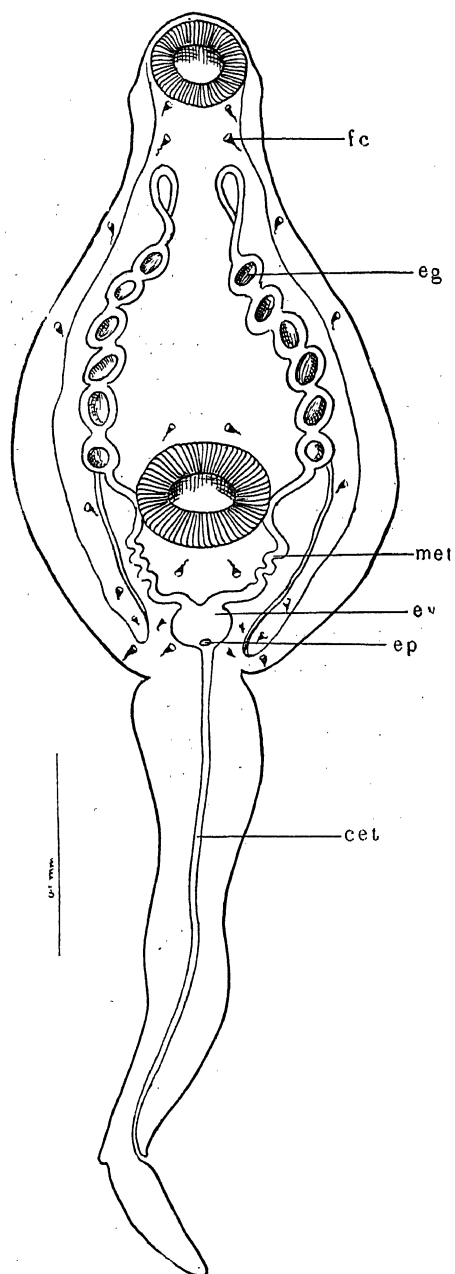
Fig. 2.—*Cercaria palustris* n. sp.—showing the excretory system.
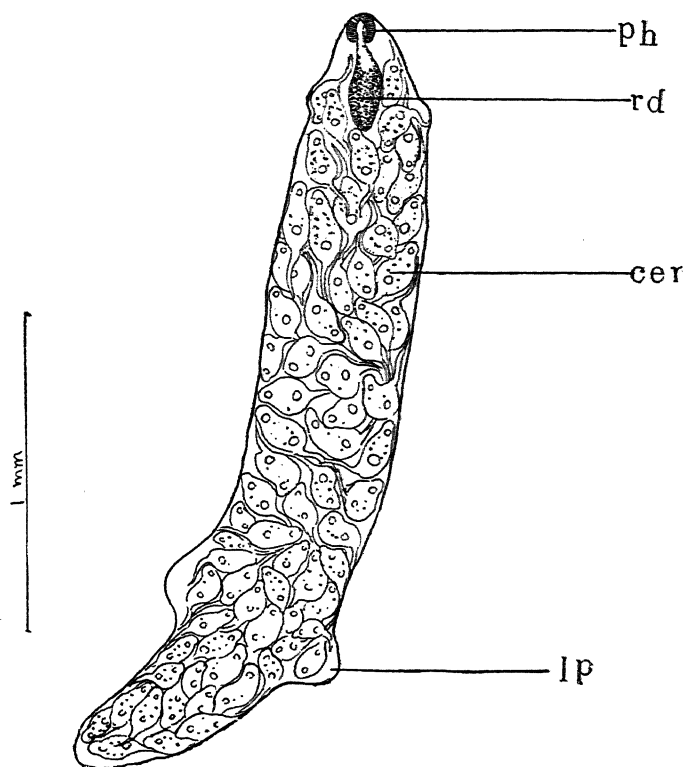
Fig. 3.— *Redia* of *Cercaria palustris* n. sp.
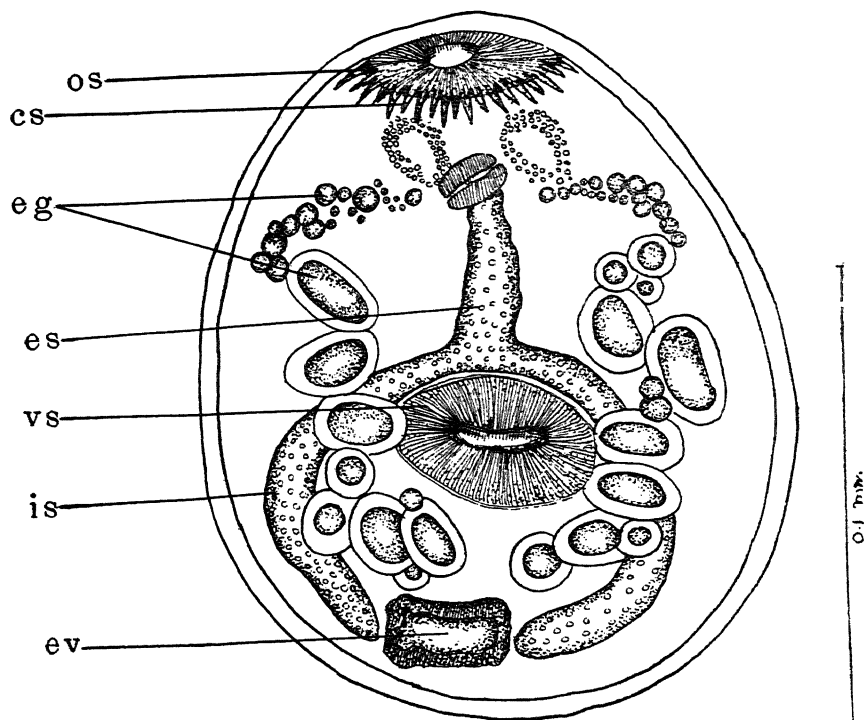


Fig. 4.—Cyst of *Cercaria palustris* n. sp.—Ventral aspect.
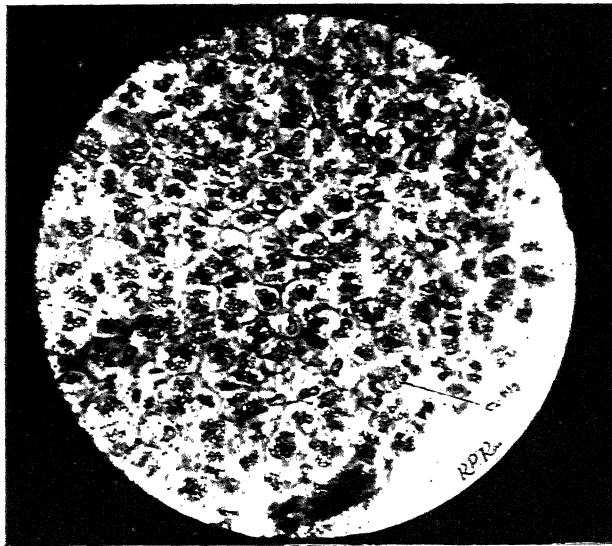
Fig. 5.—Cysts of *Cercaria palustris* n. sp.
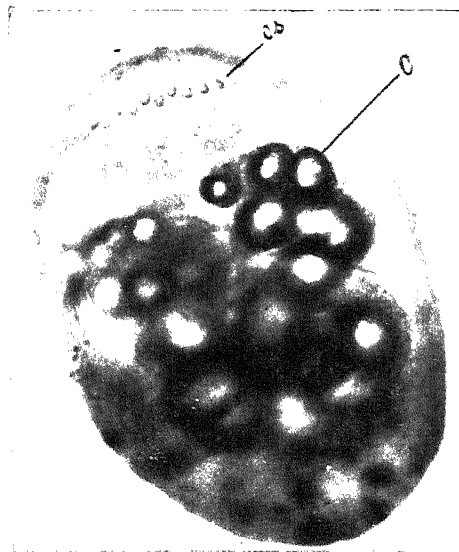
Fig. 6—Cyst of *Cercaria palustris* n. sp.

## NEW BLOOD FLUKES OF THE FAMILY SPIRORCHIDÆ STUNKARD FROM INDIAN FRESH-WATER TORTOISES WITH DISCUSSION ON THE SYSTEMATIC POSITION OF THE GENUS *COEURITREMA* N. G. AND THE RELATIONSHIPS OF THE FAMILIES OF BLOOD FLUKES.—PART I.

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### Introduction

THE blood flukes of birds and mammals constituting the family Schistosomatidæ Looss, 1899 syn. Bilharziidæ Odhner, 1912, of turtles belonging to the family Spirorchidæ Stunkard, 1921 syn. Proparorchidæ Ward, 1921, and of fishes included in the families Aporocotylidæ Odhner, 1912, and Sanguinicolidæ Graff (1907) have received much attention during the last several years, and it is well known that they form a well-defined group of closely-related forms—the Superfamily Schistosomatoidea Stiles and Hassal, 1926. Poche (1925) has, however, classified the blood flukes into two superfamilies, the Sanguinicolida containing the Spirorchidæ, Aporocotylidæ and Sanguinicolidæ and the Schistosomatida containing the family Schistosomatidæ. While I do not intend to discuss in this paper the usefulness or propriety of the two superfamilies created by Poche it is worth while to mention that ever since the publication of the memorable paper by Odhner in 1912 about the relationships of *Liolope*, *Hapalotrema*, *Bilharziella*, *Ornithobilharzia* and *Bilharzia*, the idea of the close affinities of the families of blood flukes has been gaining ground, and now it is established beyond doubt that the families Schistosomatidæ, Spirorchidæ, Aporocotylidæ and Sanguinicolidæ are closely related forming a well-defined group, and that there will not be much purpose served for a scheme of natural classification if we create two superfamilies for them. Travassos (1928) also prefers to combine the two superfamilies Sanguinicolida and Schistosomatida in one superfamily under the name of Schistosomatoidea Stiles and Hassal, 1926.

In the following pages I have described two new species of a new genus *Coeuritrema* belonging to the family Spirorchidæ, which, as will be seen from

the discussion at the end of the paper is closely related to the genera *Hapalotrema*, *Hapalorhynchus* and *Vasotrema*, and shows certain remarkable features in its anatomy, which throw much light on the origin of the Schistosomatidæ confirming the view put forward by Odhner about the close affinities of these blood flukes with the subfamily Liolopinæ of the family Harmostomidæ Odhner, 1912. It is interesting to note that this genus stands nearer *Liolope*, the type genus of the Liolopinæ than *Hapalotrema* in the general topography of its organs, presence of two testes with the ovary between them in the posterior half of the body and position of the genital opening about the middle of body length to the left side behind the ventral sucker. It appears, therefore, clear that the superfamily Fascioloidea stands connected with the superfamily Schistosomatoidea through the Harmostomidae Odhner, which is closely related to the Clinostomidæ Lühe.

## Coeuritrema lyssimus Nov. Gen., Nov. Spec.

The trematodes of this species were collected by me in 1931 and 1932 from the ventricle of the heart of soft-shelled turtles *Lyssemys punctata* at Allahabad. In all I examined sixteen turtles, out of which nine were found infected with these parasites. The rate of infection, therefore, seems to be nearly fifty per cent. The number of parasites found in a single host is generally large, more than a dozen. Three hosts were, however, found infected with 5—10 specimens each. In one case only three specimens were obtained. The distomes are more or less firmly attached to the walls of the ventricle and do not come out at once when the ventricle is opened. Some take a few minutes to come out, others a longer time; some took 20 minutes to half-an-hour to come out in the normal salt solution in which the ventricle cut into two halves was kept. When freed in salt solution they do not show any active movements; sometimes they bring their anterior and posterior ends close together and become bent in the form of a loop. They also contract slightly on the application of fixing fluids.

The body is thin and very transparent, and in preserved specimens it is generally hollowed out in the form of a shallow groove. It is somewhat conical in shape, broad and somewhat rounded near the posterior end and narrow in front of the ventral sucker ending to a blunt point at the anterior end. The size is small, 1·53—1·92 mm. in length and 0·46—0·48 mm. in greatest breadth, which lies in the region of the ovary. In the region of the intestinal bifurcation the breadth measures 0·27—0·28 mm., and in that of the ventral sucker 0·23—0·3 mm., behind which it gradually increases, measuring 0·36 mm. in the region of the genital opening and 0·46 mm. in the region of the anterior testis and the ovary, where it reaches the maximum limit. Immediately behind the ovary it slightly diminishes, measuring 0·43 mm. in the region of the posterior testis. In the region of the excretory bladder or the ends of intestinal cæca it measures 0·288 mm. One specimen measured

1ˑ37 mm. in length and 0ˑ35 mm. in maximum breadth. All the above measurements are taken from entire mounts. The hinder end is usually spatulate and flattened depending upon the state of contraction and notched in the centre, where the excretory bladder opens. Some specimens when much contracted show a curiously broad shape of the body with a more or less uniform breadth from behind the ventral sucker to the hinder end. Specimens of smaller size, as a rule, become easily contracted to assume such curious shapes. The body-wall is covered with small conical papillæ or tubercles, which extend from a little distance behind the oral sucker to the hinder end, measuring 0ˑ012 mm. in length and 0ˑ18 mm. in maximum breadth at the base. They are sparse in front of the intestinal bifurcation, but behind the acetabulum they are numerous and more closely situated. Their free ends are somewhat rounded or bluntly pointed and directed straight outwards or upwards, but not backwards like the usual chitinous spines. The small rod-shaped spines characteristic of the blood flukes are present only in the region of the genital pore and cirrus sac. There are hardly any muscle fibres visible in the body-wall, and there is no muscular layer present outside the epithelium lining the intestinal cæca.

The oral sucker is terminal and partly projects out from the anterior end above the general surface of the body, but ordinarily it is not so much protrusible as in the genus *Spirorchis.* It has a circular outline, measuring 0ˑ1—0ˑ12 mm. in diameter; occasionally it is a little longer than broad. The ventral sucker is much larger and stouter, measuring 0ˑ17—0ˑ19 mm. in diameter and 0ˑ14—0ˑ15 mm., in depth, *i.e,* a little less than twice the size of the oral sucker. In two specimens however, the ventral sucker measured 0ˑ14—0ˑ15 mm. in diameter and the oral sucker 0ˑ112 mm. in length and 0ˑ096 mm. in breadth. The ventral sucker lies close behind the intestinal bifurcation at about one-third body-length from the anterior end, occupying nearly the entire depth and a great portion of the breadth of the body, and has the form of a deep cup with a short base capable of entire protrusion from the general body surface. It is muscular, having a well-developed layer of radial muscles with an outer layer of longitudinal muscle fibres; the thickness of its wall is about double of that of the oral sucker. The pharynx is absent. The œsophagus is straight and more or less of uniform breadth, measuring 0ˑ195—0ˑ256 mm. in length and 0ˑ045—0ˑ075 mm. in breadth (in one specimen 0ˑ33 mm. long). It is closely surrounded by salivary gland cells, which are found in large numbers forming a bulbous mass before it passes into the intestinal bifurcation; the gland cells are also found in large numbers around its anterior part. The intestinal cæca turn backwards soon after their origin and extend to a little distance in front of the hinder end. They are pressed closely against, or slightly overlapped by the ventral sucker, behind which they converge inwards towards each other mesially, the left curving more deeply than the right, but soon turn outwards to occupy a lateral position. Behind the posterior testis they again undulate twice or thrice but less markedly than before. The

cæca undulate so characteristically behind the ventral sucker and the posterior testis that they enclose between them an intracæcal zone, in which the gonads with their associated ducts, vesicula seminalis and cirrus sac lie, and this I propose to call the genital field. The cæca are very narrow around and a little behind the ventral sucker. The genital opening lies dorsally to the left side of the body outside the left intestinal cæcum, half-way between the median line and the left body margin, in the region enclosed by the first characteristic loop of the left cæcum, a little distance, *i.e.*, 0·12 mm. behind the ventral sucker and a little in front of the middle of body. In a contracted specimen the intestinal cæca come so near each other behind the ventral sucker and the posterior testis that they practically meet enclosing the genital field on all sides between them, reminding one of the posterior union of the intestinal cæca in the family Schistosomatidæ. In the region of the genital pore the left cæcum comes to the right side of the median line lying close to the right cæcum (Fig 5). As seen in a transverse section passing through the genital pore the dorsal side of the body in this region is flattened and the ventral side arched.

The testes, two in number, lie in the posterior half of the body in the genital field with the ovary between them (Figs. 1 and 2). The anterior testis lies to the right side pressed against the right intestinal cæcum and close behind the cirrus sac, 0 288 mm. behind the ventral sucker, 1·04 mm behind the anterior end and 0·62 mm· in front of the hinder end It is roughly triangular or somewhat heart-shaped with a broad flat or slightly concave anterior margin and narrow rounded or somewhat bluntly pointed posterior end, and measures 0·14—0·16 mm. in length, 0·14—0 176 mm. in greatest breadth and 0·144 mm. in depth, occupying the entire depth of the body and touching the dorsal and ventral body walls. In one specimen it measured 0·096 mm. long and 0·1 mm. broad. The ovary lies between the two testes, immediately behind the anterior testis and in front of the posterior testis to the left side of the median line with its outer wall pressed closely inside the left intestinal cæcum. It is not much lobed but has a triangular or somewhat oval form with an inwardly directed process or lobe from which the oviduct arises, measuring 0·12—0·18 mm. in length, 0·05—0·1 mm. in greatest breadth and 0·051—0·11 mm. in depth ; the lobe arises from its mesial surface, a little behind or about the middle of its length. The ovary appears as a compact mass of ova of large size of 0·024—0·027 mm. diameter and easily visible under the low power of a microscope. The oviduct lies in the median line and is lined with an epithelium of cubical cells with prominent nuclei. The receptaculum seminis, 0·09 mm in length and 0·033 mm in greatest breadth, is a somewhat spherical or pear-shaped sac filled with sperms, which lies to the right side immediately in front of the posterior testis, close inside the right intestinal cæcum, in the same line with the anterior testis and just behind the level of the posterior margin of the ovary. The Laurer's canal arises from the inner side of the receptaculum seminis, near the point where the latter joins the oviduct and opens to the exterior

dorsally, slightly to the left of the median line, a little in front of the posterior margin of the ovary where it is lined with a thin layer of cuticle. The transverse vitelline ducts lie between the ovary and posterior testis in front of the receptaculum seminis, near the ventral body-wall. The vitelline reservoir lies in front of the transverse ducts in the median line or slightly to the right side and opens into the oviduct before the receptaculum seminis joins it. Both the vitelline reservoir and transverse ducts are composed of a solid mass of fairly large vitelline cells containing a prominent nucleus and vitelline granules. The oviduct after its junction with the receptaculum seminis passes into a small thin walled uterus, situated between the ovary and the anterior testis. The uterus is small and indistinguishable from the metraterm except by the absence of musculature in its walls. The metraterm is well developed and strongly muscular, measuring 0·27 — 0·32 mm. in length ; it commences between the ovary and the anterior testis, in front of which it runs parallel to the cirrus sac, crossing the left intestinal cæcum to open to the exterior at the dorsally situated genital opening. It has greatest breadth, 0·03 — 0·08 mm. in its proximal part, i.e., in the region between the ovary and anterior testis, where the ovum is usually found, while near the genital opening it measures 0·018 — 0·021 mm. in diameter. It is much more thick-walled in its distel part which lies to the left with the terminal part of the cirrus sac near the median line and the left and right intestinal cæca to the right side (Fig. 5). The posterior testis lies close behind the ovary and receptaculum seminis in the median plane of the body, 0·384 mm. distance in front of the hinder end. It is somewhat lobed, ovoid or rounded in shape, broad in front, and narrow behind, measuring 0·12 — 0·176 mm. in length, 0·084 — 0·16 mm. in greatest breadth and 0·075 — 0·12 mm. in depth, occupying the entire depth of the body and entire space between the laterally situated cæca; immediately behind it the cæca converge inwards coming near each other and joining in contracted specimens so as to mark the hinder limit of the genital field. The genital field, 0·4 mm. in length, occupies the third quarter of the body length.

The cirrus sac is large and thick-walled composed of circular muscle fibres, and is situated obliquely in the median line, in the anterior part of the genital field, with its base in close contact with and pressing the anterior face of the anterior testis near the right intestinal cæcum, and its terminal part near and outside the left intestinal cæcum on its way to the genital opening. It has a characteristic retort-shaped or flask-shaped appearance with a slight concavity anteriorly to the right side, in which lies closely pressed against it the vesicula seminalis. It measures 0·15 – 0·24 mm. in length, 0·045 — 0·084 mm. in greatest breadth a little in front of the basal end and 0·06 mm. in depth ; in front of the middle of its length it measures 0·048 — 0·06 mm. in breadth. The vesicula seminalis is nearly spherical, pear-shaped or oval in outline, situated outside the cirrus sac and pressed closely against it in the concavity in its right wall, between it and the right intestinal cæcum, in level with and immediately behind the genital pore

It has thin parenchymatous walls and is filled with sperms, measuring 0˙048—0˙057 mm. in length, 0˙024—0˙042 mm. in greatest breadth and 0˙045 mm. in depth; it becomes narrower near its hinder end, where it enters the cirrus sac. The pars prostatica lies within the cirrus sac as a narrow tube surrounded by a vacuolated mass of prostate gland cells. The cirrus is well developed and easily protrusible. When protruded it is seen to be continuous with, though somewhat constricted off from, the terminal portion of the cirrus sac, which lies within the genital atrium It is an elongated cylindrical organ, swollen at the free terminal end and narrow at the base, lying flat on the dorsal surface of the body near the left body margin, and measuring 0˙09—0˙1 mm. in length, 0˙075—0˙09 mm. in greatest breadth at the end and 0˙033 mm. in breadth at the base (Fig. 5). The cirrus sac opens to the right and the metraterm to the left side in the small genital atrium.

The vitellaria commence behind the acetabulum and terminate near the hind end just behind the blind ends of the intestinal cæca. They lie mainly outside the intestinal cæca covering them dorsally and ventrally, but immediately behind the acetabulum and the posterior testis, i.e., in the region of the cæcal loops they extend inwards uniting mesially, leaving, however, entirely uncovered the genital field and the excretory bladder. The follicles are large in size and closely crowded together. The transverse ducts arise between the ovary and the posterior testis and unite to form in front the vitelline reservoir, which lies ventrally to the oviduct. Only one ovum is contained at a time in the uterus or in the proximal part of the metraterm. The ovum is large, somewhat oval in shape, and produced into a narrow filament at each end, measuring 0˙168 mm. in length with filaments, 0˙096 mm. without filaments and 0˙027—0˙03 mm. in greatest breadth. In one specimen the ovum had one end produced into a small bluntly pointed filament and the other end indistinctly curled; in this case the entire ovum measured 0˙096 mm. in length.

The excretory bladder is short but prominent, situated at the posterior end of the body in the median plane, behind and a little in front of the blind ends of the intestinal cæca. It consists of a short median stem, which bifurcates anteriorly at about the level of or a little in front of the blind ends of the cæca, into two short cornua or lobes lying near and parallel to each other. The main stem also gives off laterally two lobes behind each other on each side near the bifurcation. The tubular bladder and its diverticula are lined by a layer of columnar epithelial cells with no muscular layer outside. The excretory opening is terminal, situated in the middle of the notch at the posterior end of the body.

Habitat: Ventricle of heart.

Host: *Lissemys punctata* syn. *Emyda granosa*. Locality: Allahabad, India.

### Coeuritrema Odhnerensis Nov. Spec.

One specimen of this blood fluke was obtained from the ventricle of the heart of *Lissemys punctata* at Allahabad in October 1931. The body is thin, delicate

and very transparent, measuring 1˙5 mm. in length, 0˙224 mm. in maximum breadth in the genital field, *i.e.*, from the genital opening to the hinder limit of the posterior testis, 0˙176 mm. in breadth in the region of the ventral sucker and 0˙16 mm. in that of the intestinal bifurcation. It is narrow and elongated with bluntly-pointed ends, measuring 0˙09 mm. in breadth at the anterior end and 0˙06 mm. at the posterior end; just behind the oral sucker it slightly broadens attaining a breadth of 0˙1 mm. The posterior end is not broad and notched in the middle as in *Coeuritrema lyssimus*, from which this species differs markedly in the shape of its body (Fig. 7). The body-wall is entirely free from tubercles or papillæ, which are well developed in the other species.

The oral sucker is larger than the ventral sucker, measuring 0˙087 mm. in length and 0˙075 mm. in breadth. It lies terminally at the anterior end and is much protrusible. The ventral sucker is delicate, much smaller and thinner with poorly developed musculature than that of *C. lyssimus*, measuring 0˙06 mm. in length and 0˙072 mm. in breadth, and lies a little in front of the hinder limit of the first third body length. The pharynx is absent. The œsophagus measures 0˙27 mm. in length and 0˙08 mm. in maximum breadth, and is surrounded by salivary gland cells, which lie in much larger numbers around the intestinal bifurcation. The intestinal cæca run backwards as soon as they arise, surrounding closely the ventral sucker and terminate a little distance in front of the hind end, just in front of the bifurcation of the short main stem of the excretory bladder. Behind the ventral sucker, at a distance of 0˙075 mm. from it, they bend inwards towards the median line, the left more markedly than the right, to form the characteristic, loops, which lie near each other separated by a narrow median region of 0˙015 mm. diameter. Behind the genital field, *i.e.*, the posterior margin of the posterior testis they do not undulate to form loops as in the other species, but they run straight near and parallel to each other, ending 0˙15 mm. distance in front of the hind end.

The excretory opening lies at the hind end of the body. The excretory bladder is narrow and tubular, situated at the hind end just behind the blind ends of the intestinal cæca; the main stem of 0˙1 mm. length is a little longer than that of the other species and bifurcates into two short cornua, close behind the blind ends of the cæca. One small rather inconspicuous lateral lobe is given off on each side from the main stem just behind the point of bifurcation.

The genital opening lies dorsally to the left side in the region enclosed by the loop of the left intestinal cæcum, close outside the latter, 0˙99 – 0˙1 mm. distance behind the ventral sucker and a little in front of the middle of the body; it lies a little more forward than in *C. lyssimus*. The testes, two in number, lie in the posterior half of the body with the ovary between them in the genital field and are distinctly lobed. The anterior testis lies immediately behind the cirrus sac, 0˙12 mm. distance behind the genital opening, somewhat in the median line, more to the right than the left side near the right intestinal cæcum by the intervening metraterm. It is irregularly lobed and rounded, measuring 0˙105 mm. in diameter. The ovary

lies between the testes and has a characteristic flask-shaped outline with the neck part directed mesially and the main body part of an oval shape, 0'084 mm. long and 0'03 mm. broad, situated to the left side with its outer margin in close contact with the left intestinal cæcum and its longitudinal axis parallel to the length of the body. The narrow mesially directed part 0'039 mm. long and 0'027 mm broad, arises from the middle of its length and is continued into the oviduct. The receptaculum seminis filled with sperms lies to the right side close inside the right intestinal cæcum with its narrow anterior part curved mesially, opposite to the ovary immediately in front of the posterior testis, and measures 0'054 mm. in length and 0'036 mm. in greatest breadth near its basal end. The transverse vitelline ducts and the vitelline reservoir lie as in the other species close behind the ovary, between it and the posterior testis. The posterior testis lies median, 0'454 mm. in front of the hinder end and immediately behind the ovary and the receptaculum seminis; it is lobed like the anterior testis with nearly equal long and broad diameters, measuring 0'096 mm. in length and 0'102 mm. in greatest breadth, and occupies the entire space between the two cæca. The gonads occupy nearly third quarter of the body length.

The cirrus sac is well developed with stout muscular walls, situated close in front of and pressing behind the anterior testis ; it is crescent-shaped with a deep concavity in its right wall, which lies median with the vesicula seminalis opposite to it near the right intestinal cæcum. It is approximately 0'18 mm. long and 0'054 mm. broad in its greatest diameter in the region a little in front of the concavity. It consists of a small basal part of 0'075 mm. length lying transversely and large vertical part lying adjacent to the left intestinal cæcum. The vesicula seminalis of an oval shape lies to the right side touching the right intestinal cæcum opposite to the middle part of the cirrus sac, and measures 0'054 mm. in length and 0'036 mm. in greatest breadth. The cirrus is well developed and protrusible. When protruded it shows a chitinous rugose surface without spines or hooks and has a characteristic stick-shaped form with a stumpy curved handle like terminal portion of 0'033 mm. length and 0'027 mm. breadth; the main part measures 0 045 mm. in length and 0'018—0'02 mm. in breadth.

The uterus lies between the mesial neck part of the ovary and the posterior margin of the anterior testis; it is not distinguishable from the metraterm, into which it soon passes. The metraterm is well developed with thick muscular walls, situated to the left side in close contact with the left intestinal cæcum, between it on one side and the cirrus sac and the anterior testis on the other, measuring 0'25 mm. in length and 0'03 mm. in breadth. Near its terminal end it crosses ventrally the left intestinal cæcum to open into the shallow genital atrium. Only one ovum is contained in the uterus or the proximal part of the metraterm, which in consequence is much dilated. The ovum is oval in shape and produced into a coiled filament at one end and indistinctly seen elongated filament at the other, measuring 0'09 mm. in length without filaments and 0'03 mm. in greatest breadth.

The vitellaria are extensive, situated laterally overlapping the intestinal cæca and uniting mesially behind the ventral sucker, in the region between it and the genital pore, and in the intracæcal region behind the posterior testis to the blind ends of the cæca, leaving entirely free the genital field. They commence at the intestinal bifurcation and terminate a little behind the blind ends of the cæca at about the bifurcation of the short stem of the excretory bladder.

Habitat: Ventricle of heart.

Host: *Lissemys punctata* syn. *Emyda granosa.*

Locality: Allahabad, India.

### Remarks on the Species of the Genus Coeuritrema

It will be apparent from the foregoing description that *Coeuritrema odhnerensis* and *Coeuritrema lyssimus* resemble each other closely in the anatomy and topography of organs and therefore must be referred to the same genus. Both the species are characterised by the presence of two suckers, a long œsophagus surrounded by gland cells, intestinal bifurcation close in front of ventral sucker, intestinal cæca reaching near the hind end and forming characteristic loops behind the ventral sucker, dorsal sinistral position of the genital opening behind the acetabulum near or a little in front of the middle of body length, testes two in number with the ovary between them, well developed cirrus sac situated in front of the anterior testis with the vesicula seminalis outside it near the right intestinal cæcum, a stout eversible cirrus, well developed muscular metraterm and short uterus containing a single large ovum with one or two polar filaments situated in front of the ovary, strongly developed vitellaria overlapping the cæca and uniting mesially behind the acetabulum and posterior testis leaving free the genital field, and a small but prominent excretory bladder with a short median stem, two anterior cornua and lateral lobes, situated at the hind end.

The important features in which *C. odhnerensis* differs from *C. lyssimus* and which entitle it to the rank of a different species are:—

(1) Shape of the body; elongated and narrow in *C. odhnerensis*, much broader behind ventral sucker with a broad posterior end in *C. lyssimus*.

(2) Absence of papillæ in the body wall.

(3) Oral sucker larger than ventral sucker; reverse condition in *C. lyssimus*.

(4) Intestinal cæca not undulating behind posterior testis.

(5) Testes irregularly lobed.

(6) Characteristic shape of ovary; flask-shaped in *C. odhnerensis*, somewhat triangular or conical in *C. lyssimus*.

(7) Crescentic shape of cirrus sac; retort shaped in *C. lyssimus*.

(8) Shape of protruded cirrus; stick-shaped in *C. odhnerensis*, broad and flattened with a narrow base in *C. lyssimus*.

(9) Anterior limit of vitellaria, intestinal bifurcation in *C. odhnerensis*, posterior border of acetabulum in *C. lyssimus*.

F. 2

(10) Character of the ovum.

(11) Main stem of excretory bladder a little longer, with one pair of small rather inconspicuous lateral lobes.

## Diagnosis of the Genus Coeuritrema N. G.

Hapalotreminæ : Hermaphrodite distome blood flukes; delicate musculature.

Body elongated, narrow or broad behind ventral sucker; size very small; body wall with or without small papillæ; oral sucker protrusible; ventral sucker protractile and retractile, situated at about one third body length from anterior end. Pharynx absent; œsophagus long surrounded by salivary gland cells which are numerous near its posterior extremity; intestinal bifurcation close in front of ventral sucker; intestinal cæca reaching a little in front of hind end and forming characteristic loops behind ventral sucker in region of genital opening, left cæcal loop more pronounced. Genital opening dorsal, sinistral close behind ventral sucker near middle of body length close outside left cæcum. Testes two in number with ovary between them, situated in third quarter of body, intracæcal and usually lobed; anterior testis lying to the right, immediately behind cirrus sac and close in front of ovary; posterior testis median, immediately behind ovary and receptaculum seminis. Ovary conical or flask-shaped, situated to the left with transverse vitelline ducts close behind it; vitelline reservoir in front of transverse ducts. Receptaculum seminis pear-shaped, rounded or oval situated to the right near right cæcum, immediately in front of posterior testis. Cirrus sac large, muscular and crescent shaped or retort shaped with a concavity in its right wall, situated immediately in front of anterior testis. Vesicula seminalis small, external, and to the right side near right cæcum opposite to the cirrus sac. Cirrus well developed, without spines. Metraterm well developed and muscular, situated in front of ovary and to the left side of anterior testis and cirrus sac Uterus short, indistinguishable from metraterm except by the absence of muscula-ture, containing a single large ovum bearing filaments at ends. Vitellaria well developed lateral, overlapping the cæca, uniting mesially behind ventral sucker in the region between it and genital opening, and behind posterior testis, leaving entirely free the genital field. Excretory bladder small and tubular at hinder end with a short median stem provided with one or two pairs of lateral lobes and dividing near blind ends of cæca into two small but prominent cornua.

Habitat : Ventricle of heart.

Host : Water tortoises, *Lissemys punctata*. Locality : Allahabad, India.

*Type species.—Coeuritrema lyssimus* sp. n.

## Previous Work on the Blood Flukes of the Family Spirorchidae Stunkard, 1921

The family Spirorchidæ contains the blood flukes of turtles assigned to the following genera:—*Hapalotrema* Looss, 1899, *Spirorchis* MacCallum, 1918 syn. *Proparorchis* Ward, 1921, *Henotosoma* Stunkard, 1923, *Hæmatotrema* Stunkard, 1923, *Hapalorhynchus* Stunkard, 1923, *Vasotrema* Stunkard, 1926, *Unicæcum* Stunkard, 1927, *Spirhapalum* Ejsmont, 1927 and *Diarmostorchis* Ejsmont, 1927. Stunkard in 1921 divided this family into two sub-families, Spirorchinæ Stunkard and Hapalotreminæ Stunkard which he defined. In the former sub-family have been included the genera *Spirorchis*, *Henotosoma*, *Hæmatotrema*, and *Unicaecum*; in the latter, the genera *Hæmatotrema*, *Hapalorhynchus* and *Vasotrema*. *Spirhapalum* and *Diarmostorchis* are considered as connecting genera between the two sub-families by Ejsmont, who has consequently expressed an opinion of dropping the sub-families.

Looss in 1899 created the genera *Hapalotrema*, *Bilharziella* and the family Schistosomidæ. He pointed out, in the course of discussion about these genera, that the points of resemblance between them do not indicate a close relationship, but merely adaptations due to a constantly similar environment. Odhner in his memorable paper in 1912 included *Hapalotrema* in the sub-family Liolopinæ of the family Harmostomidæ, which he created with diagnosis. He derived the Bilharziidæ, now known as the Schistosomidæ from the Liolopinæ through such forms as indicated by the following type series:—*Liolope*, *Hapalotrema*, *Bilharziella*, *Ornithobilharzia*, *Bilharzia*. Ward (1921), on the basis of a close similarity between *Proparorchis* and *Hapalotrema*, removed the latter genus from the Liolopinæ and included it with his Proparorcidæ in his family Proparorchidæ, now well known as the Spirorchidæ. After emphasising the points of difference between *Spirorchis* and *Hapalotrema* he concluded that if the posterior region in the latter genus be reduced by the failure of the posterior testis to develop with the correlated cessation of growth in the posterior of the worm, the distome would show a condition of reproductive organs with the ovary and its associated genital ducts near the hind end as met with in the genus *Spirorchis*. Stunkard in 1921 accepted the main idea advanced by Ward about the close relationship of the two genera of blood flukes of turtles, *i.e.*, *Spirorchis* and *Hapalotrema*, which he included in the family Spirorchidæ named after the type genus *Spirorchis* on the basis of priority. He also divided this family into two sub-families as mentioned above. Ejsmont in 1927 while describing his new genus and species *Spirhapalum polesianum* assigned *Spirorchis blandingi* MacCallum to a new genus *Diarmostorchis*, as it differed from all the other species of the genus *Spirorchis* in possessing the hindmost testis behind the ovary. He considered this genus to be a connecting link between the blood flukes of American and European turtles. As the genera *Spirhapalum* and *Diarmostorchis* combine in themselves the characters of the Spirorchinæ and Hapalotreminæ, he expresses the opinion of dropping the sub-families. According

to the relative position of the ovary and the testes Ejsmont has shown an ascending series of genera with a gradual transformation from *Spirorchis* having about 10 preovarian testes to *Hapalorhynchus* having only two testes with the ovary between them, and traces the forward position of the genital opening with the correlated ducts and the forward position of the ovary in *Hapalotrema, Hapalorhynchus* and the Schistosomidæ from their position near the hind end in *Spirorchis* through such transition genera as *Diarmostorchis* and *Spirhapalum* as the result of their gradual displacement towards the anterior end. In the final stages, *i.e.,* in *Hapalorhynchus* and Schistosomes where the culminating point is reached, the genital ducts have quitted their primitive position behind the testes and at about the level of the ovary, crossed the latter and reached the anterior testis ,with the genital opening shifted still more forwards, *i.e.,* in front of the latter.

Stunkard in 1921 and 1923 had expressed the opinion that the Spirorchidæ occupies an intermediate position between the Schistosomidæ and the Aporocoty-lidæ and that the Schistosomes are to be derived through them from the Aporocoty-lidæ, rather than from the Harmostomidæ as maintained by Odhner. Poche (1925), however, does not agree with Stunkard's view saying that the absence of suckers and the presence of follicular testes in the Sanguinicolidæ and the Aporocotylidæ warrant against it. In 1926 Stunkard created the new genus and species *Vasotrema amydæ* and in 1928 added two more species, *i.e., Vasotrema attenuatum* and *Vasotrema robustum* to it. In 1927 he created the genus *Unicæcum,* including it in the sub-family Spirorchinæ and emended the sub-family and family diagnosis. He also pointed out that *Unicaecum* suggested the creation of a new sub-family for it and that sooner or later a new classification of the family may be deemed necessary. In 1928 in his paper on the new observations on the genus *Vasotrema,* he gave a review of the knowledge of the blood flukes and accepted Ejsmont's conclusions about *Diarmostorchis* and *Spirhapalum* as the connecting genera between the sub-families Spirorchinæ and Hapalotreminæ. He also stated that the study of the genus *Vasotrema,* which possesses one large testis situated behind the ovary con-firms entirely the theory about the phylogenetic relationships of blood flukes propounded by him and Ejsmont, and pointed out that the relative position of the genital organs demonstrates that no other family of trematodes presents such great morphological variations as the Spirorchidæ in the number of suckers, in the form of the œsophagus and digestive cæca, in the number and position of the testes, in the form and situation of the ovary, in the presence or absence of Laurer's canal, Mehli's gland and cirrus sac and finally in the position of the vesicula seminalis and the genital pore. The existence of intermediate forms between the whole connected series of genera, however, shows that they all belong to one and the same family.

From the above historical account it would be clear that there are two views about the evolution of the families of blood flukes, one expressed by Odhner, *i.e.,* the Schistosomidæ are derived from the Liolopinæ of the Harmostomidæ through

*Hapalotrema*, and the other put forward by Stunkard and Ejsmont that the Spirorchidæ stands in an intermediate position between the Schistosomidæ and the Aporocotylidæ and that the Schistosomes are evolved through them from the Aporocotylidæ rather than from the Harmostomidæ. In the opinion of these authors the sub-family Spirorchinæ represents the primitive condition of reproductive organs of the family Spirorchidæ.

We may so far anticipate our own conclusions arrived at in the subsequent discussion as to say, that the Hapalotreminæ of the Spirorchidæ forms the central stock, from which are evolved on the one hand the Schistosomidæ and on the other the degenerate blood flukes of the families Aporocotylidæ and Sanguinicolidæ, and that the genus *Coeuritrema* has relations on the one hand with the Liolopinæ and on the other with *Hapalotrema*, *Hapalorhynchus*, *Vasotrema* and the Schistosomidæ.

## Discussion on the Systematic Position of the Genus *Coeuritrema* and the Relationships of the Families of Blood Flukes.

It will be apparent from the description of the species and the generic diagnosis that *Coeuritrema* belongs to the family Spirorchidæ and the sub-family Hapalotreminæ, which it resembles in the following features :—

1. Presence of protrusible oral and ventral suckers.
2. Acetabulum situated near the end of anterior third of body.
3. Absence of pharynx.
4. Long œsophagus surrounded by salivary gland cells which are densely crowded near the intestinal bifurcation ; intestinal cæca reach near hinder end.
5. Testes two in number with the ovary between them as in *Hapalorhynchus*. In *Hapalotrema* the two testes are divided into a large number of follicles so as to form two testicular masses, one in front of the ovary and the other behind it. In *Vasotrema* the anterior testis is absent, *i.e.*, suppressed, and the posterior large and much lobed.
6. Genital pore situated to the left on the dorsal side, behind ventral sucker about the middle of body length. In *Vasotrema*, however, it is sinistral and ventral and not dorsal.
7. Ovary, receptaculum seminis, Laurer's canal and ootype situated near or a little behind middle of body.
8. Muscular cirrus sac present. *Hapalorhynchus* is the only genus in the sub-family, in which the cirrus sac is absent.
9. Protrusible cirrus well developed, absent in *Hapalorhynchus*.
10. Vesicula seminalis outside cirrus sac.
11. Uterus short; muscular metraterm well developed. Only one ovum present in uterus or proximal part of metraterm and discharged singly.
12. Ovum large with filaments at ends.
13. Vitellaria well developed, lateral and medial to the cæca throughout most

of their course.  In *Coeuritrema* and *Vasotrema robustum* they unite mesially behind ventral sucker and posterior testis (in the latter only one testis present).

14.  Excretory vesicle short and tubular situated near hind end with a short median stem dividing into two cornua or lobes much behind posterior testis.

There is a close resemblance amongst the various genera of the sub-family Hapalotreminæ, which  we following Stunkard sharply separate from the Spirorchinæ.  We do not agree with Ejsmont that as *Spirhapalum* resembles in one or two features the genus *Hapalotrema*, the division of the Spirorchidæ into sub-families should be dropped.  The presence of one testis follicle behind the ovary and the presence of a ventral sucker in *Spirhapalum* should not be considered as features of sufficient importance so as to give it the position of an intermediate genus between the two sub-families.  Though the presence of two testes or testicular masses, one in front and the other behind the ovary, is one of the characteristic features of the Hapalotreminæ, the topography of all the genital organs taken together in *Spirhapalum* resembles closely that of the Spirorchinæ, and we are inclined to think that the presence of one testis follicle behind the ovary is an example of reversion rather than a step towards the evolution of the arrangement and position of the testes met with in the Hapalotreminæ.  The sinistral dorsal or ventral position of the genital opening about the middle of body length and the forward position of the ovary with its associated ducts and the cirrus sac near or a little in front of the middle of body are important features of the Hapalotreminæ, to which due importance should be given in deciding this question.  Stunkard has pointed out that the number and position of the testes are very variable in the family, and we go a little further and say that they show variability even in the two sub-families.  In *Vasotrema*, which Stunkard includes in the Hapalotreminæ there is only one large testis present behind the ovary ; in *Unicæcum*, which he includes in the Spirorchinæ there is one large testis present in front of the ovary.  In *Hapalotrema* the two testes separated by the ovary are divided to form two follicular masses, whereas in *Hapalorhynchus* and *Coeuritrema* they are not divided into follicles.  *Spirhapalum* and *Diarmostorchis* possess the ovary with its associated ducts, genital opening and the cirrus sac near the hind end as in *Spirorchis* and therefore should be included in the Spirorchinæ, which comprises both monostomes and distomes.  The presence of a ventral sucker in *Spirhapalum* should  also  not  be  considered  as  a  great  distinction  from the Spirorchinæ, as in a number of species very closely related to *Spirorchis*, which I shall  describe in a subsequent paper the ventral sucker is present; and, moreover, it is well known that the presence or absence of a ventral sucker by itself is not to be considered as a feature of more than specific or generic rank.

Among  the Hapalotreminæ *Coeuritrema* shows in itself some characters of all the three well-known genera of the sub-family as has been pointed above.  From *Hapalotrema* it differs in the intestinal cæca forming a characteristic loop behind the ventral sucker in the region of the genital opening, testes not divided into

follicles so as to form two testicular masses one in front and the other behind the ovary and the genital opening situated in front of the gonads as in *Hapalorhynchus* and not behind the anterior testes in level with the ovary. In *Vasotrema* also the genital pore lies in level with the ovary, but the anterior testis or testicular mass is absent in this genus. In *Hapalotrema* and *Vasotrema* the vesicula seminalis lies in the median plane in front of the ovary, whereas in *Coeuritrema* and *Hapalorhynchus* it lies in front of all the gonads, smaller and to the right side in the former, median and much larger in the latter. *Hapalorhynchus* resembles *Coeuritrema* in the number of the testes and their position one in front and the other behind the ovary, position of the genital opening and the vesicula seminalis in front of the gonads, in the characteristic loop formed by the left intestinal cæcum, the extent of the vitellaria and the hosts being fresh water turtles, but the enormous development of the prostate and the absence of the cirrus sac and the cirrus distinguishes it from the latter. In *Coeuritrema* the cirrus sac is directed forwards with the basal end lying in front of the anterior testis, whereas in *Vasotrema* and *Hapalatrema* it is directed backwards, a condition which is also met with in the genus *Bilharziella* among the Schistosomidæ. The vesicula seminalis is small and lies to the right side of the cirrus sac in *Coeuritrema*, but it is large and median in all the other genera of the Hapalotreminæ and in *Bilharziella*. In *Liolope* also the vesicula seminalis, though large, lies to the right side near the right cæcum. The medial union of the vitellaria behind the ventral sucker and posterior testis in *Coeuritrema* resembles closely that in *Vasotrema robustum*.

Odhner has discussed the affinities of *Hapalotrema* with *Liolope* and *Bilharziella* and considers it to form a connecting link between the families Harmostomidæ and Schistosomidæ. The close affinities of *Coeuritrema* with *Hapalotrema* have been already pointed out, and now I contend that Coeuritrema stands much nearer *Liolope* than *Hapalotrema*.

The essential features in which it resembles *Liolope* are the following :—

(1) Suckers well developed ; ventral sucker usually larger.

(2) Testes two in number with the ovary between them, situated in posterior half of body, and not divided into follicles.

(3) Genital opening in front of gonads, near or a little in front of middle of body and strongly shifted to the left side.

(4) Cirrus sac well developed and situated behind ventral sucker and in front of anterior testis.

(5) Vesicula seminalis external and to the right side of cirrus sac near right intestinal cæcum in front of gonads.

(6) Metraterm well developed.

(7) Excretory system.

(8) Large size of ovum.

It seems that all these features were present in the ancestral blood fluke related to *Liolope*, when it took to a life in the blood of the ventricle of the heart and arteries of an amphibian or reptilian host. *Coeuritrema* is the only genus in the Hapalotreminæ which possesses all these characters in addition to those which it holds in common with the other genera of the subfamily as adaptations due to a common environment such as the absence of pharynx, long oesophagus surrounded by salivary gland cells and lined internally with cuticle, delicate body with scantily developed musculature, short female duct and formation and extrusion of ova one by one. We think that in the ancestral blood fluke the cirrus sac was laterally directed towards the sinistral genital opening with the vesicula seminalis to its right side as in *Liolope*. From this condition we can derive on the one hand the forwardly directed cirrus sac of *Coeuritrema* with the genital opening in front and on the other the backwardly directed cirrus sac of *Hapalotrema*, *Vasotrema* and male *Bilharziella*. It is interesting to note that *Coeuritrema* resembles male *Bilharziella* more closely than *Hapalotrema*, though it has not got the testes divided into follicles. The two genera resemble remarkably in the position of the genital opening behind the ventral sucker to the left side a little in front of the middle of body. The mesial bending of the intestinal cæca behind the ventral sucker and the posterior testis in *Coeuritrema* represents in an incipient condition the formation of the posterior cæcum by the caudal union of the intestinal cæca either in front of the testes or behind them, which is typical of the family Schistosomidæ. In *Bilharziella* the caudal fusion of the cæca has taken place behind the genital opening, *i.e.*, in front of the testes, while in *Ornithobilharzia* it has taken place behind the testes a little distance in front of the hinder end, equivalent to the region behind the posterior testis in *Coeuritrema*, where the cæca bend so much mesially towards each other that in contracted specimens they sometimes meet together in the median line. The formation of mesial loops by the cæca behind the ventral sucker and the posterior testis certainly throws some light on the formation of the caudal cæcum in the Schistosomidae.

There is no doubt that the ancestor of the Schistosomidæ, though it closely resembled *Coeuritrema* had its testes divided into follicles somewhat like those of *Hapalotrema* and this tendency was strongly inherent in its immediate ancestors. With the separation of sexes, which took place when the ancestral Schistosomes inhabited the portal and mesenteric veins of homothermal vertebrates *i.e.*, birds and mammals, the follicular testes formed together one mass, which in some genera became located in front of the caudal union as in *Ornithobilharzia* and in the other behind it as in *Bilharziella*. The strongly muscular and eversible ventral sucker and well developed metraterm of *Coeuritrema* and the other Hapalotreminæ confirm the above conclusions about these relationships. The presence of papillæ in the body wall of *C. lyssimus* recalls the same in some species of the genus *Schistosoma*. In the Balharziellinæ the uterus is short and contains a single ovum as in the Spirorchidæ and the gynæcophoric canal is absent or imperfectly formed. It seems

apparent then that the Bilharziellinæ are derived from the Hapalotreminæ through an ancestral form closely related to *Coeuritrema*. From a form closely related to *Bilharziella* we can derive *Ornithobilharzia*, *Austrobilharzia* and *Heterobilharzia* in which the cirrus sac is present and the uterus contains only one ovum at a time. The suckers are also well developed in these genra. From forms closely related to them can be derived the genus *Schistosoma*, which has lost the cirrus sac and in which the genital pore lies in the median line, the number of testes is relatively small and the uterus contains a large number of ova.

The origin of the Spirorchinæ can be traced from a form somewhat like *Hapalotrema*, in which the anterior testicular mass developed preponderantly keeping pace with the much greater rate of growth of the part of body in front of the ovary so that the latter with the associated ducts and the hinder testis (not divided into follicles) came to occupy a position near the hind end of the body as in *Spirhapalum*. The form from which the Spirochinæ has arisen, however, differed from *Hapalotrema* in the important point that while the anterior testis was divided into follicles, the posterior testis remained undivided. The culminating point was reached when the posterior testis became entirely suppressed so that the ovary with its associated ducts came to lie near the hind end as in *Spirorchis*.

That this is likely is borne out by the fact that in *Vasotrema* the anterior testis is suppressed and the posterior testis considerably increased in size. It seems that *Spirhapalum* stands near the end of a series of changes in the backward shifting of the ovary and its correlated ducts as we find in the genus *Spirorchis*. The Hapalotreminæ of the Spirorchidæ forms the central stock, from which are evolved on the one hand the Spirorchinæ and on the other the Schistosomidæ and *Coeuritrema* represents a form closely related to the ancestor through which the Hapalotreminæ are derived from the Liolopinæ. It is well known from the study of different groups of animals that evolution does not take short straight cuts along one line as Stunkard and Ejsmont contemplate according to their theory of the phylogenetic relationships of blood flukes in an ascending series from the Aporocotylidæ through the Spirorchinæ to the Hapalotreminæ and the Schistosomidæ. On the other hand ample evidence is afforded from the study of various groups of animals that evolution always takes place in divergent lines from a central generalised type and this we maintain applies with equal emphasis in the case of the families of blood flukes. We should not expect our ancestral blood fluke to possess more than two testes, as this is the most usual number for the order Digenea. The division of these two testes, into follicles should be considered as a secondary condition which is met with in a few other families besides the families of blood flukes, as for instance, in some genera of the Pronocephalidæ. Among all the sub-families and families of blood flukes Hapalotreminæ is the only subfamily in which two genera *i.e.*, *Coeuritrema* and *Hapalorhynchus* show the primitive number of testes ; besides in the third genus *i.e.*, *Hapalotrema* these two testes have become divided into follicles. In the spirorchinæ and the

F. 3

Aporocotylidæ a large number of testes *i.e.*, testis follicles are present, which is certainly a secondary and not a primary condition, it is, therefore, but natural for us to consider this latter condition as having been evolved from the condition of the testes in the Hapalotreminæ.

In the same way we can derive from the ancestral form closely related to *Coeuritrema* and *Hapalotrema* through a form like *Spirorchis* the family Aporocotylidæ and the more degenerate Sanguinicolidæ, which we shall discuss in a subsequent paper.

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## Explanation of Plates and Key to Lettering used in Figures

Figures 1-6.   *Coeuritrema lyssimus.* --

1. Dorsal view of a specimen.
2. Microphotograph of entire mount.   Dorsal view.
   Leitz Eyepiece X ; Leitz Objective 3, 10 X.
3. Microphotograph of horizontal longitudinal section showing genital
   organs.   Leitz Eyepiece O; Zeiss Objective 40 D.
4. Microphotograph of transverse section through ventral sucker.   Leitz
   Eyepiece 3; Leitz Objective 6lg, 45 X.
5. Microphotograph of transverse section through genital opening show-
   ing everted cirrus, terminal part of cirrus sac, metraterm and
   intestinal cæca.
   Leitz Eyepiece 3: Leitz Objective 6lg, 45 X.
6. Microphotograph of transverse section through cirrus sac. metraterm
   and vesicula seminalis.
   Leitz Eyepiece 3; Zeiss Objective 40 D.

Figure 7. *Coeuritrema odhnerensis.*

7. Microphotograph of entire mount.   Dorsal view.
   Leitz Eyepiece 3 ; Leitz Objective 3, 10 X.

a t., anterior testis ; c.s , cirrus sac ; ex.b., excretory bladder ; i.c., intestinal cæcum ;
l.i.c., left intestinal cæcum ; 1. l.i., loop of left intestinal cæcum ; m., metraterm ; o.s,
oral sucker ; œs, œsophagus ; ov., ovary ; p.t., posterior testis ; r.s., receptaculum
seminis ; r.i.c., right intestinal cæcum ; s.g., salivary gland cells ; t.c.s., terminal
part of cirrus sac ; v.s , ventral sucker ; ves s., vesicula seminalis ; vit., vitellaria.
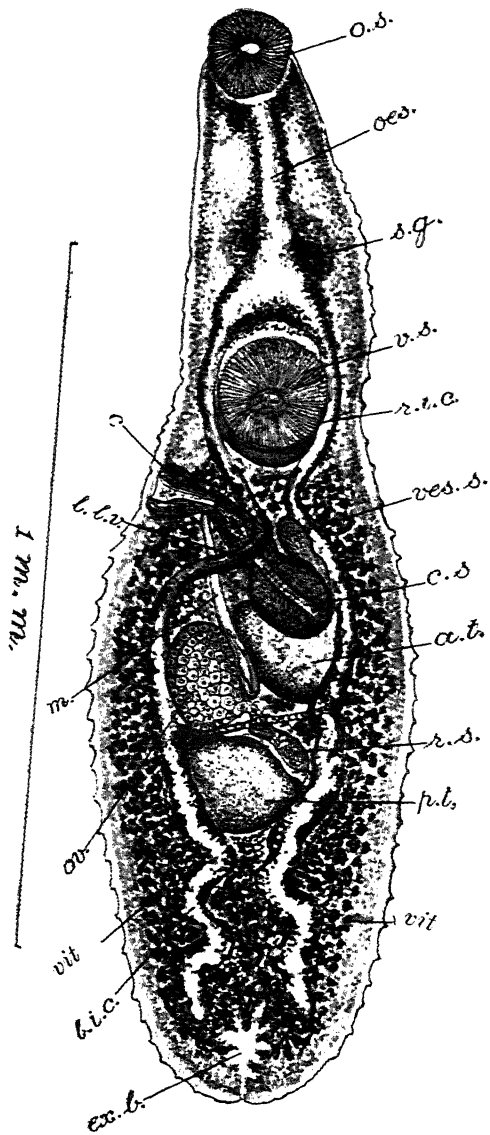
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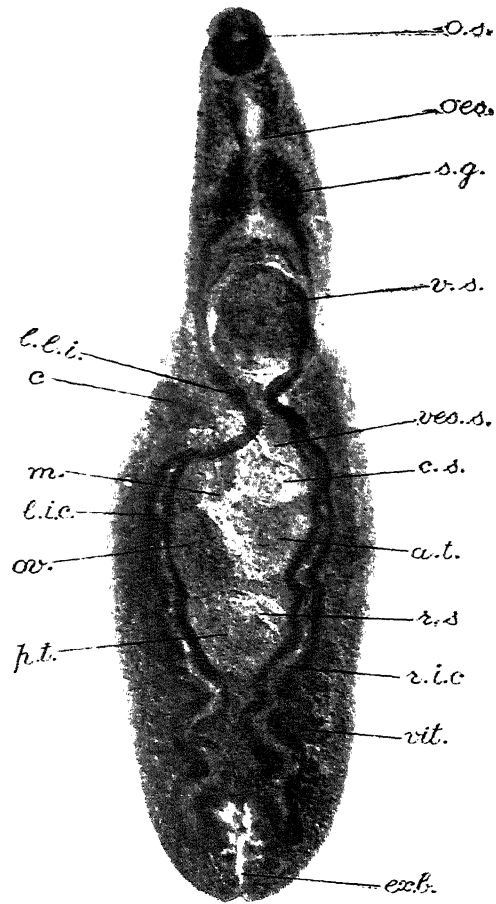


Fig 2
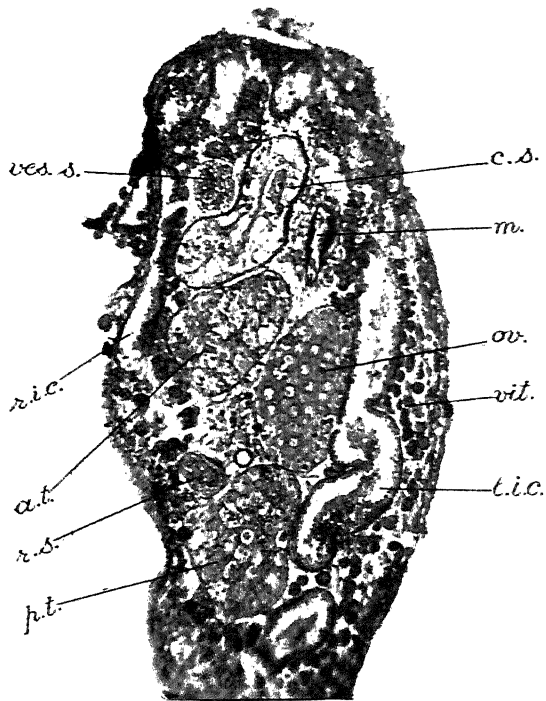
Fig 3



Fig 4
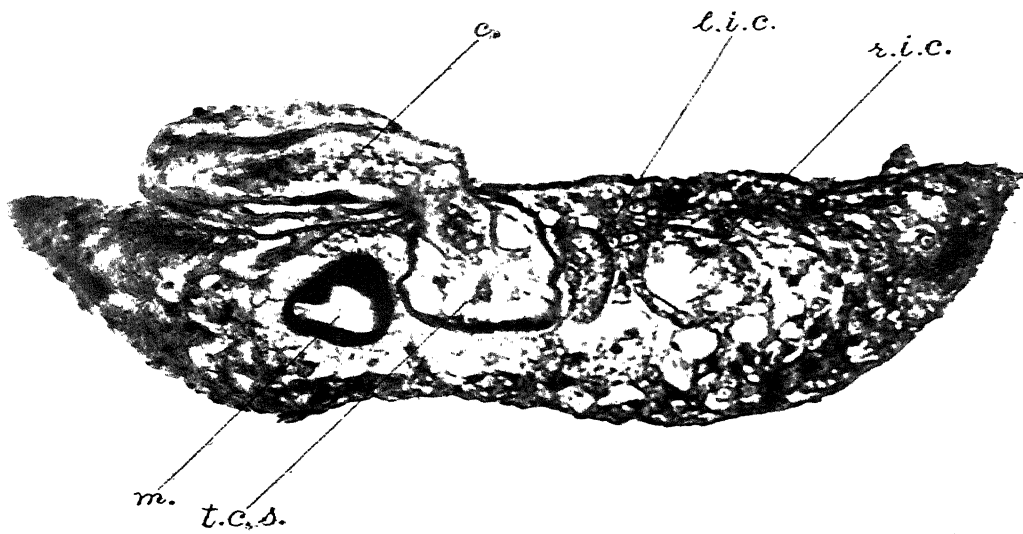


Fig 5
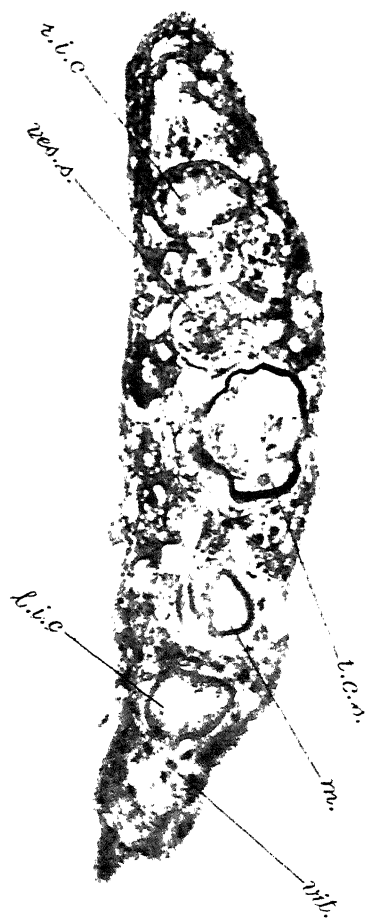
Fig. 6
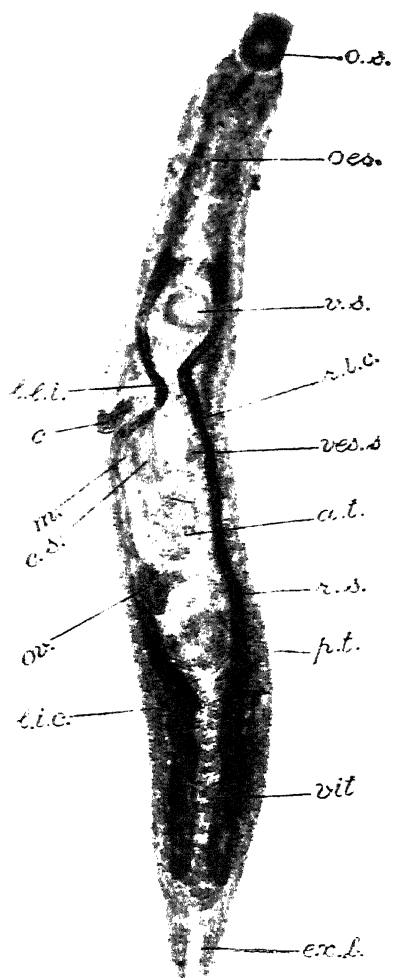
Fig. 7

# CONCLUSIONS ON THE STRENGTH AND NATURE OF BINDING FROM THE CONTINUOUS ABSORPTION SPECTRUM

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In recent years a large number of calculations on the Heat of Dissociation particularly of diatomic molecules, were made from the structure of the absorption and emission band spectra. The calculations can be carried out with great exactness if the spectral position of band convergence can be correctly determined. If light having the frequency corresponding to this convergence frequency be absorbed then we add to the molecule an amount of energy which is equivalent to that required for the electron-spring together with as much oscillation energy as is necessary for just disrupting the molecule into its constituent atoms, so that, after separation, the constituents have no kinetic energy relative to each other. If the absorption extends only to a part of the band-spectrum, and not up to the convergence limit, then the position of the band convergence can be extrapolated more or less exactly from the frequencies of the band heads. If, on the other hand, the coupling relations are such that, together with the energy necessary for the electron spring, a somewhat larger amount of oscillation energy is also added than what is necessary for dissociation, then we observe a continuous spectrum, and from its position we can obtain the maximal value of the heat of dissociation. Owing to the fact that alkali halides in the gaseous state give us such values which agree with values obtained independently the utility of the process has been over-estimated.

Even in the first application of the considerations regarding the significance of the continuous absorptions of the alkali halides,[1] the authors discussed the grounds due to which the procedure may give inaccurate results. Clearly these

results cannot be taken as sufficiently accurate and now-a-days they can be formulated in a more precise way. In the following, therefore, we want to define our position in respect to this question by using the experimental results of other authors working in the field. It depends very closely on the problem whether we have to deal with ionic or atomic binding On this complex question results have already been given in the abovementioned works of the author[2], but these are to be partly extended and partly curtailed. This shall be done in the following : —

At the time we wrote our first series of papers such molecules were defined as ionic molecules in which by following the oscillation terms of the ground state up to the convergence limit they can be shown to decompose into ions. If they decompose into atoms we call them as atomic molecules. The amount of energy required for splitting up into ions is always greater than that for splitting into neutral atoms. Therefore the potential energy curves for these two states intersect. The intersection of the curves can under certain circumstances cause some ambiguity when we want to follow up the oscillation systems to convergence, and therefore sometimes the distinction between atomic and ionic molecules may turn out to be illusory. But no such case is known up to this time, and theoretically, it is not expected as well.

Up to this time these definitions have been found to be unambiguous. This classification does not coincide with the division of molecules into homopolar and heteropolar groups. Ionic molecules are always heteropolar, the atomic
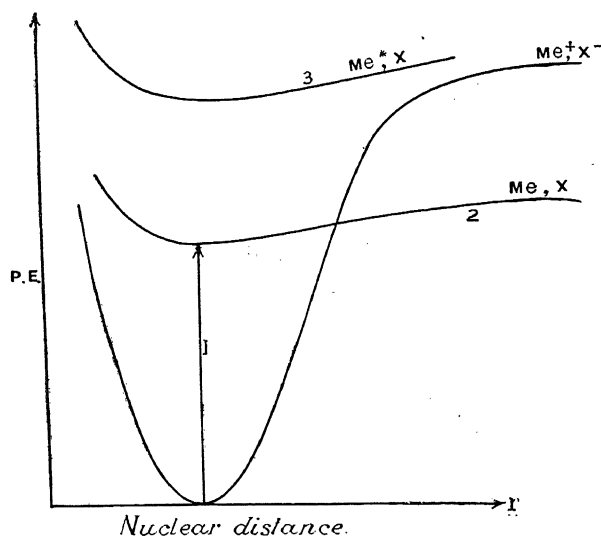


Fig. 1

molecules, on the other hand, may sometimes possess some electric moment and may be at other times nonpolar.

As is clear from the above potential-energy curves the state of an atom-molecule always represents an excited state of ionic molecule when transition takes place from the fundamental state to the first excited state. Due to absorption of light, then, in the limit, we have dissociation into normal atoms (Arrow 1). The authors have designated the occurrence of such transitions as a criterion for ionic binding. It is now held that this deduction is limited in its application for Heitler and Herzberg[3] have shown that there are exceptional cases in which the fundamental state of a molecule is formed out of a normal and an excited atom. Therefore an excited state of the molecule may consist of normal atoms. Further, Brown[4] has shown, in a series of work on the absorption spectra of halogens, that in the case of diatomic halogens which are to be regarded as atomic molecules, optical decomposition into two atoms takes place very feebly. The above criterion, there-fore, represents a necessary, but not a sufficient condition for the case of an ionic binding. As a typical limiting case of pure ionic binding we can take the case in which the binding forces are caused entirely by coulombian forces. That is, forces due to resonance interaction are not present, the polarisation having only a very small influence on the binding. Then a transition from the fundamental state of the ionic molecule to the state of the atomic molecule, which is equivalent to the transfer of an electron from kation to the anion will completely destroy the coulombian binding and, with that, practically the whole binding force will dis-appear. On account of this reason we have a part of the potential energy curves 2 and 3 running almost parallel to the abscissa. That is why the minimum is not at all prominent in the case of ionic molecule. If the atom molecules are bound by forces of resonance interaction then the excited molecules show curves with very pronounced minima, and with a steep left hand side branch indicating repulsive force.

The fact that the curve for the excited alkali halides rise from a flat form almost perpendicularly over the minimum of the ground state, causes, as has been discussed already, the occurrence of the continuous absorption spectra, which stretch over relatively short wavelength regions.[5] A well-defined long wavelength limit does not exist and is not to be expected even when we consider the part of the spectra which is produced by the deepest oscillation state of the molecule. If we want to use the limiting long-wavelength frequency of the continuous absorption we have to utilise the point from which a steep rise of the absorption coefficient begins and we obtain only an upper value for the cor-responding heat of dissociation. We can draw conclusions from the part of the curve of absorption coefficients running asymptotically on the longer side of this limit when the absorption by the oscillation levels belonging to the fundamental state can be quantitatively taken account of. But even when these not very easy calculations are taken into account it is unjustified to give values of the heat of dissociation correct up to the tenth part of a k. cal, as we very often find in literature. Further, out of an extremely faint tail of the long wavelength side of the absorption curves, we can draw no conclusion on the nature

of binding, as Rollefson and Booker[6] as well as Dutta[7] had done in the case of hydrogen halides.

These authors believe that our former reasonings for regarding the hydrogen halides as atom molecules* are contradicted by the fact that when the gas pressure is very high, a feeble absorption is observed up to a wavelength, which is smaller than the energy of excitation of the hydrogen halides to a normal hydrogen and excited halogen   Even when (what does not seem to be probable according to the above considerations) an extremely feeble absorption would lead from fundamental states to normal atoms, we have at most an analogy to the atom-molecules of halogens, but not an analogy of that of the ionic molecules of alkali halides.

The continuous absorption of 3, 4, 5 atomic molecules, and whether in their compositions, they can be regarded as ionic or atomic molecules on the basis of their spectra, have been investigated in a series of papers by Saha[8] and his co-workers.   It has been found that from the long wavelength limit we always calculate a longer value of energy than what is necessary for the separation of the normal atom from the normal-rest.   This behaviour is not in contradiction to the above conception.   Even in the case of a tri-atomic ionic molecule, which can be represented by the formula $X^- Me^{++} X^-$, with electron spring from one $X^-$ to the kation the binding of this atom ceases, and simultaneously the coulombian attraction forces between the second anion and kation are strongly altered, so that the rest $X^- Me^+$ remains in a strongly oscillating state.   An analogous condition holds in a stronger measure also for the ionic molecules with larger atom numbers. Conclusions on the energy of dissociation and on the nature of binding cannot therefore be drawn only out of the long wavelength limit of continuous absorptions of polyatomic molecules without further work.

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* The principal ground for classifying the alkali halides as ionic molecules was due to their having two maxima in the absorption spectra separated by a distance corresponding to the energy of excitation of the halogen constituents.

# NORMAL FREQUENCY SPECTRA

By J. S. BADAMI,

PUNDOLI POL. SURAT.

In the analysis of a complex spectrum it is often necessary to find out pairs of lines whose frequencies have a constant difference. The usual method of choosing two suitable lines, finding their frequency difference, and searching for other pairs having that difference, though quite exhaustive and accurate, is lengthy, especially when the correct constant-difference to be searched for is not known. Another method is to plot the frequencies along a line. The intensity of any spectral line might be represented by the length of a line drawn perpendicular to the previous line from the corresponding point. To search for constant frequency differences then is to search for equidistant lines. This might be done by means of a scale, or, more conveniently by sliding one such chart over another and noting coincidences. The rough idea of intensities is also a guide in the selection of pairs.

It would be much more convenient if an enlarged picture of the spectrum could be had on a normal frequency scale. In a paper on "The reproduction of prismatic spectrum photographs on a uniform scale of wave-lengths" Fowler and Eagle[1] have noted that the method indicated in the paper could also be applied to produce normal frequency spectra, but they gave no details. The details for this as applied to both prismatic and grating spectra are given below.

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Fig. 1 is reproduced from Fowler and Eagle's paper, in which it is described as follows :—



Fig. 1

"Let L be a lens which will bring equidistant points lying on a plane AB perpendicular to the axis of the lens, into focus as a system of equidistant images on another plane CD. In the diagram let $EL = u$, $FL = v$, $PG = x$, $PH = y$, $QJ = X$, $QK = Y$, $\angle SEB = \phi$, $\angle QFD = \psi$, $PE = s$ and $QF = l$."

The following results can be easily derived as shown in the paper:

$$v = \frac{fu}{u-f} \qquad \cdots \qquad \cdots \qquad \cdots \qquad \cdots \qquad \cdots \quad (1)$$

$$\frac{Y}{X} = \frac{y}{x} \cdot \frac{v}{u} \qquad \cdots \qquad \cdots \qquad \cdots \qquad \cdots \qquad \cdots \quad (2)$$

From (2) since $y/x$ is constant along PS, Y/X is also constant, *i.e.*, all points lying on PS will be brought into focus on another straight line QT;

$$\tan \psi = \frac{v}{u} \tan \phi \qquad \cdots \qquad \cdots \qquad \cdots \qquad \cdots \qquad \cdots \quad (3)$$

$$l = \frac{fks}{u-f-s.\sin\phi} \qquad \cdots \qquad \cdots \qquad \cdots \qquad \cdots \quad (4)$$

where $\qquad K = \sqrt{(\cos^2\phi + \frac{v^2}{u^2}\sin^2\phi)}$

$$\frac{dl}{ds} = \frac{fk(u-f)}{(u-f-s\sin\phi)^2} \qquad \cdots \qquad \cdots \qquad \cdots \quad (5)$$

If we have a prismatic spectrum on the plate PS for which the wavelength at a distance $s$ from the centre of the plate is given by the Cornu-Hartmann formula,

$$\lambda = \lambda_0 + \frac{c}{s+s_0}, \qquad \text{we have,} \quad \frac{d\lambda}{ds} = -\frac{c}{(s+s_0)^2}$$

the wave-number $v = \dfrac{10^8}{\lambda}$ $\qquad \therefore \dfrac{dv}{d\lambda} = \dfrac{-10^8}{\lambda^2}$

or substituting for $\lambda$, $\qquad \dfrac{dv}{d\lambda} = -\dfrac{10^8(s+s_0)^2}{\{\lambda_0(s+s_0)+c\}^2}$

Hence, for the spectrum on QT we have,

$$\frac{dv}{dl} = \frac{dv}{d\lambda}\cdot\frac{d\lambda}{ds}\cdot\frac{ds}{dl} = -\frac{10^8(s+s_0)^2}{\{\lambda_0(s+s_0)+c\}^2} \times \frac{-c}{(s+s_0)^2} \div \frac{fk(u-f)}{(u-f-s.\sin\phi)^2}$$

$$= \frac{10^8 c}{fk(u-f)}\left\{\frac{u-f-s\sin\phi}{\lambda_0(s+s_0)+c}\right\}^2 \qquad \cdots \quad (6)$$

Now $dv/dl$ gives the variation of wave-number with respect to length along the enlargement. If it is required that each unit length of the enlargement should correspond to a fixed number of units of wave-number equal to N say, then $dv/dl$ must be constant and equal to N.

For this to be so $(u-f-s\sin\phi)$ must always be proportional to $\{\lambda_0(s+s_0)+c\}$, i.e., $(u-f) = -\sin\phi(c+\lambda_0 s_0)/\lambda_0$ for all values of $s$.

Then $\qquad\qquad\qquad\left\{\dfrac{u-f-s\sin\phi}{\lambda_0(s+s_0)+c}\right\}^2 = \dfrac{\sin^2\phi}{\lambda_0^2} \qquad \cdots \quad (7)$

$$k^2 = \cos^2\phi + \frac{v^2}{u^2}\sin^2\phi = \cos^2\phi + \frac{f^2}{(u-f)^2}\sin^2\phi \qquad \text{by (1)}$$

$$k^2(u-f)^2 = f^2\sin^2\phi + \cos^2\phi.\frac{\sin^2\phi}{\lambda_0^2}(c+\lambda_0 s_0)^2 \qquad\qquad (8)$$

By (7) & (8) we get from (6):

$$N^2 = \left(\frac{dv}{dl}\right)^2 = f^2 \cdot \frac{10^{15} c^2 \sin^2\phi}{\lambda_0^2 \{f^2 \lambda_0^2 + (c + \lambda_0 s_0)^2 \cos^2\phi\}} \quad \dots \dots \quad (9)$$

$$\therefore \quad N^2 f^2 \lambda_0^2 \{f^2 \lambda_0^2 + (c + \lambda_0 s_0)^2\} = \sin^2\phi \{10^{16} c^2 + N^2 f^2 \lambda_0^2 (c + \lambda_0 s_0)^2\}$$

$$\therefore \quad \sin^2\phi = \frac{N^2 f^2 \lambda_0^2 \{f^2 \lambda_0^2 + (c + \lambda_0 s_0)^2\}}{10^{16} c^2 + N^2 f^2 \lambda_0^2 (c + \lambda_0 s_0)^2} \quad \dots \dots \dots \quad (10)$$

all the constants involved on the right-hand side being known, $\sin\phi$ and therefore $\phi$ can be evaluated.

$\psi$ is given by $\tan\psi = (v/u)$. $\tan\phi = \{f/ u - f)\}$. $\tan\phi$ by (1) and (3) and substituting for $(u - f)$ we have

$$\tan\psi = -\frac{f\lambda_0 \tan\phi}{\sin\phi(c + \lambda_0 s_0)} \quad \dots \dots \dots \dots \quad (11)$$

$u$ is given by

$$u - f = -\frac{\sin\phi}{\lambda_0}(c + \lambda_0 s_0) \quad \dots \dots \dots \dots \quad (12)$$

As $(u - f)$ must be positive we should only take the negative values of sin from (10).

$v$ is given by

$$v = \frac{fu}{u - f} = -\frac{fu \lambda_0}{\sin\phi(c + \lambda_0 s_0)} \quad \dots \dots \dots \dots \quad (12a)$$

If we have a grating spectrum on the plate PS for which the wavelength is given by the linear formula $\lambda = \lambda_0 + cs$, we have $d\lambda/ds = c$,

$$\frac{dv}{dl} = \frac{dv}{d\lambda} \cdot \frac{d\lambda}{ds} \cdot \frac{ds}{dl} = -\frac{10^5}{\lambda^2} \cdot c \cdot \frac{(u - f - s \sin\phi)^2}{fk(u - f)}$$

substituting for $\lambda^2$, $\frac{dv}{dl} = -\frac{10^5 c}{fk(u - f)} \cdot \frac{(u - f - s \cdot \sin\phi)^2}{(\lambda_0 + cs)^2} \quad \dots \dots \dots \quad (13)$

for this to be constant equal to M say, $(u - f - s \cdot \sin\phi)$ should always be proportional to $(\lambda_0 + cs)$, i.e, for all values of $s$, $(u - f) = (-\lambda_0 \sin\phi)/c$ and then,

$$\frac{(u - f - s \cdot \sin\phi)^2}{(\lambda_0 + cs)^2} = \frac{\sin^2\phi}{c^2} \quad \dots \dots \dots \dots \quad (14)$$

$$k^2(u - f)^2 = (u - f)^2 \left\{\cos^2\phi + f^2 \frac{\sin^2\phi}{(u - f)^2}\right\} = \sin^2\phi \left\{f^2 + \frac{\lambda_0^2}{c^2} \cdot \cos^2\phi\right\} \dots \quad (15)$$

With the help of (14) and (15) we get from (13)

$$M^2 = \left(\frac{dv}{dl}\right)^2 = \frac{10^{16} c^2}{f^2} \cdot \frac{\sin^2\phi}{c^2} \cdot \frac{1}{f^2 c^2 + \lambda_0^2 \cos^2\phi} \quad \dots \dots \dots \quad (16)$$

giving
$$\sin^2\phi = \frac{M^2 f^2 (\lambda_0{}^2 + f^2 c^2)}{10^{10} + N^2 f^4 \lambda_0{}^2} \qquad \ldots \ldots \ldots \ldots \quad (17)$$

$\psi$ is given by $\tan \psi = \dfrac{f}{u-f} \tan\phi = -\dfrac{fc \tan \phi}{\lambda_0 \sin\phi} = -\dfrac{fc}{\lambda_0 \cos\phi} \qquad \ldots \ldots \ldots \quad (18)$

$u$ is given by $(u-f) = \lambda_0 . \sin\psi/c \qquad \qquad \ldots \ldots \ldots \ldots \quad (19)$

and $\qquad v = fu/(u-f) = -fcu/\lambda_0 . \sin\psi \qquad \ldots \ldots \ldots \ldots \quad (20)$

As in prismatic spectra the negative value of $\sin\phi$ is to be taken. As $s$ is the distance measured from the centre of the plate, $\lambda_0$ represents the wavelength at the centre.

Taking a particular example for the prismatic spectra, the interpolation formula was given by $\lambda = 1025\cdot78 + 811922\cdot8/(s + 588\cdot005)$, $s$ being measured from the centre of the plate, increasing in direction of decreasing wave-lengths and expressed in millimetres. N was taken equal to 10 units of wave-number per 1 mm.; the focal length $f = 7\cdot8$ ins. $= 198\cdot12$ mms.

$$\lambda_0 = 1025\cdot78, \text{ and } c = 811922\cdot8.$$

Substituting in (10), we get after some calculation,

$$\phi = 2^\circ\ 3', \psi = 8^\circ\ 11', u = 247\cdot45 \text{ mms., and } v = 993\cdot80 \text{ mms.}$$

Wavelengths in air were used in the interpolation formula in the above example. For greater accuracy wave-lengths corrected to vacuum should be used.

It will be observed that the formulæ thus deduced for the conversion of prismatic and grating spectra to the scale of normal frequencies would be exact if the dispersions were accurately represented by the Cornu-Hartmann and linear formulæ respectively. In practice these are only close approximations and in neither case can exact reproductions on the normal frequency scale be made. The results obtainable, however, are of sufficient accuracy to be of service in the preliminary examination of spectra for the detection of recurring frequency differences.

For very complex spectra the method is not useful, for the large number of lines, and the comparatively wide limits which have to be assigned to the accuracy of the constant differences searched for, make the number of apparently equal differences too large.

However, for spectra with moderate number of lines, the method is to be recommended, especially, when the differences to be searched for are not well known.

In order to test the results experimentally, an apparatus not much different from that of Fowler and Eagle was used. The frame ordinarily used for carrying the negative in the enlarging apparatus was supplemented by one which could

be rotated about a horizontal axis at the centre  The plate was mounted vertically. To the side, at the lower end of the original frame, was screwed a millimetre scale while the rotating frame was provided with a pointer.  Thus the $\angle \phi$ could be easily set.  In front of the usual copying board of the enlarging apparatus, at its top, was hinged a board which could thus be made to rotate round a horizontal axis.  A scale was attached to the usual copying board and the rotating board carried a pointer allowing for the adjustment of $\angle \psi$.  The distance $u+v$ was adjusted by moving the enlarging lens.

In conclusion it is a pleasure to express my thanks to Prof. A. Fowler in whose Laboratory at the Imperial College of Science and Technology, this work was carried out.

*Reference*

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# ABSORPTION SPECTRA OF SOME HALOGEN-DERIVATIVES OF METHANE

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## Introduction

Up to the present time not much work has been done on the absorption spectra of polyatomic molecules, though the need for such investigations has been keenly felt, as they promise to furnish supplementary grounds on which the structural models of these molecules may be built. In such works difficulty is encountered both in respect of experimental technique, as well as in the interpretation of results. In case of organic substances the main difficulty consists in maintaining a suitable range of vapour pressure of the absorbing gas at ordinary temperatures (e.g., for $CHCl_3$, $CHBr_3$, $CHI$, etc...), and sometimes in obtaining the substance in a state of high degree of purity (e.g., for $CH_3Cl$, $C_2H_5Cl$, etc.) which is essential for getting any correct result. No less difficulty is felt in experimenting with polyatomic inorganic compounds; thus, for example, the commonest among them, the oxides of the alkali metals have to be heated in a very high temperature-furnace for getting appreciable vapour pressure. Besides, many of these substances, both organic and inorganic (e.g., bromoform, nitrous oxide, etc.), attack mercury, india-rubber, and sealing wax, so that it becomes a matter of considerable difficulty to maintain and measure the pressure of the absorbing gas column. Nevertheless important works on the absorption spectra of many alkyl halides have been done by Herzberg[1] and Schiebe, Mecke[2], Iredale[3] and Mills and others, and those of saturated halides of multivalent elements have been studied by Saha[4], Datta, Deb[5], and others in this laboratory.

According to Franck and Kuhn's well-known hypothesis, the limit of continuous absorption towards the long wavelength side of the spectrum corresponds to the beginning of photo-dissociation of the molecule. On this basis it is possible to

determine the strength of the carbon-halogen bond from the study of the beginning of continuous absorption of saturated alkyl-halides and some other organic compounds of carbon, hydrogen, and halogens. This has necessarily added a special importance to the study of the absorption spectra of polyatomic substances.

While most of the early observers have found that the absorption spectra of the alkyl-halides consist entirely of continuous absorption beginning from a long wavelength limit and extending towards the short wavelength side within a region $\lambda$ 3000 to $\lambda$ 2000, band-absorptions in the case of $CH_3Cl$ have been found by Herzberg and Scheibe, and more recently in the case of $CCl_4$, $CHCl_3$, $CH_2Cl_2$ ... by A. Henrici[5] in the region $\lambda$ 2000 to $\lambda$ 1400. Saha and Datta, in their study of the absorption spectra of a number of tetra-halides including $CCl_4$, have tried to make the generalisation that the energy of photo-chemical dissociation of such compounds is one-fourth the total atomic heat of formation; or, in other words, in $CCl_4$ the total heat of formation is equally distributed among the four halogen-bonds of carbon. Iredale and Mills from the photometric study of the absorption limit of $CH_3I$, $C_2H_5I$, etc., have attempted to emphasise that the C atom in such alkyl-halides exists in $2s2p^3\,{}^5S$ state, and not in the $2s^22p^2\,{}^3P$ state as assumed by Herzberg and Scheibe. They have tried to show further that their fresh determinations of absorption limits of these substances are consistent with this view. Regarding most of these works it may be remarked, however, that the experimental methods employed in the determination of the long-wavelength limit, which is rather ill-defined, are not above criticism. On the other hand, from the isolated data that can be procured from these works on some of the halogen derivatives of methane (e.g., $CCl_4$, $CH_3Cl$, etc.) it is not possible to arrive at any definite conclusion regarding the gradual formation of these derivatives by the replacement of H atoms of methane successively by one, two, or more Cl-atoms—a subject which has acquired considerable importance from the study of the dielectric moments[7] of these compounds. The purpose of the present paper has been to provide a systematic study of the di-, tri- and tetra-halogen derivatives ($CH_2Cl_2$, $CHCl_3$ and $CCl_4$) of methane in relation to the value of the C-Cl bond energy, as calculated from the measurement of the beginning of their continuous absorption.

The nature of photo-chemical dissociation taking place in these cases is a matter of some uncertainty. Herzberg and Scheibe, in their investigations on the continuous and discontinuous light absorption by methyl halides, have assumed the process of dissociation as—

$$CH_3I + h\nu = CH_3 + I^*$$
or
$$= CH_3^* + I$$
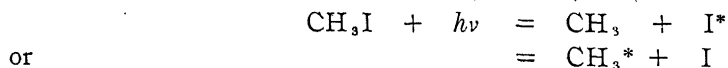
where M* denotes an excited state of M, i.e., the effect of light absorption is the dissociation of the compound into a normal and an excited radical. Iredale and Mills[3] in their papers on $CH_3I$, $C_2H_5I$ ... definitely assert that the products of

dissociation for such compounds are one *neutral alkyl radical and an excited halogen atom.*

Assuming this to be true the dissociation of $CH_3Cl$ and $CCl_4$ is supposed to consist of —

$$CH_3Cl + h\nu = CH_3 + Cl^*$$
$$CCl_4 + h\nu = CCl_3 + Cl^*$$
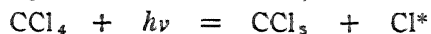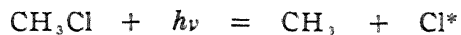
*i.e.,* in each case the effect of light absorption is the dissociation of a C-Cl bond, and the energy $h\nu$ required for this purpose marks the beginning of the continuous absorption. Extending the same principle to the intermediate compounds of the series we may write —

$$CHCl_3 + h\nu = CHCl_2 + Cl^*$$
$$CH_2Cl_2 + h\nu = CH_2Cl + Cl^*$$
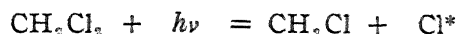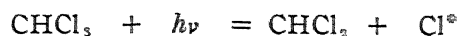
The potential energy curves for the states of the molecules before and after dissociation are represented in Fig. 1. In the normal state A the molecule is supposed to consist of a central C atom electrically bound to four other (H or Cl)
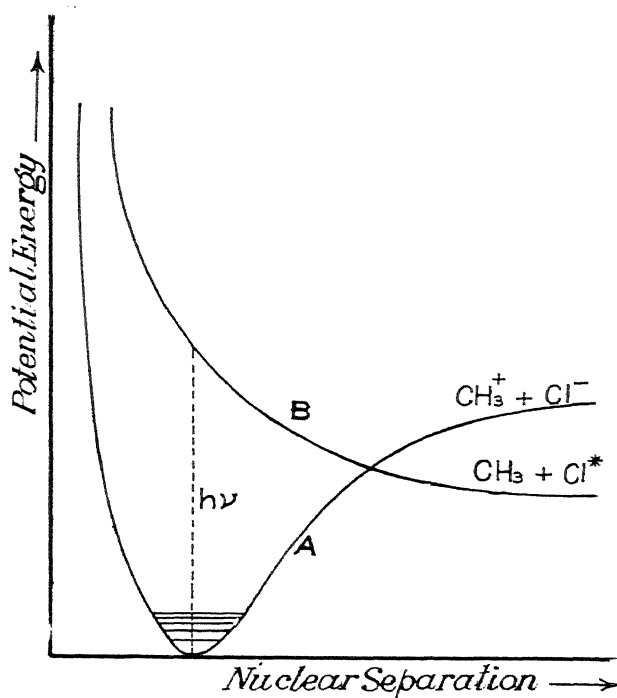


Fig. 1

atoms, which have each taken up an extra electron from the atom, which has thus lost four of its outer electrons. The second state B is brought about in each case by the transference of an electron from the $\overline{Cl}$- ion   to   the $C^+$ -ion by light

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absorption. Since the same amount of energy $h\nu$ is required for this electronic transition in the molecule in each case, the beginning of continuous absorption for all members of the series should be precisely the same. The observations embodied in the present paper show a certain amount of disagreement from this conclusion.

## The Experimental Procedure

The method employed for the study of the beginning of the continuous absorption of $CCl_4$, $CHCl_3$, $CH_2Cl_2$ is that previously used by Datta[5] in this laboratory. The substance under investigation, usually a liquid, is contained in a bulb $B$ (Fig. 2), and its vapour is enclosed at room temperature in a pyrex glass tube about one metre long, and closed at both ends by quartz plates $P$, $P$. Light was allowed to pass through the tube from a continuous source $S$ (a hydrogen discharge tube)
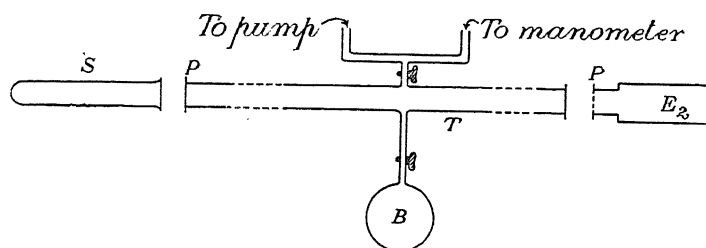


Fig. 2

placed co-axially with the absorption tube, and the spectrum of the transmitted light was photographed in the usual way by an $E_2$-quartz spectrograph. The pressure inside the absorption tube could be adjusted by means of a vacuum pump attached to the tube, and read directly by a manometer. As almost all the compounds examined attacked india-rubber and sealing-wax, difficulty was experienced in connecting the bulb and sealing the quartz plates to tube ends. The difficulty was overcome by making the side-connections entirely of glass and using mainly plaster of Paris as the substance for sealing. A copper arc was used as a source of comparison spectrum. Different photographs were obtained for the same substance with different pressures of the absorbing gas. Continuous spectrum was obtained in each case, the beginning of which was found visually to shift with pressure.

## The Determination of the Limit

The exact determination of the beginning of continuous absorption from these photographs is a matter of considerable difficulty, as the limit is not at all well-defined, and moreover, because the visible limit seems to change with the pressure of the gas and the length of the absorbing column. In fact, Franck and Kuhn in a private note addressed to Prof. Saha have pointed out that from theoretical considerations the limit of continuous absorption ought to extend over

a short region of wavelength rather than corresponding to a sharp limit. For the electronic transition which is associated with the photo-dissociation of the compound may take place not only from the ground state of the molecule, but also from a number of closely lying vibrational states of excitation (Fig. 1).

The visual method sometimes employed is obviously very inaccurate, as the decrease in intensity actually begins much earlier (towards the longer wavelength side) than can be detected by the eye. Iredale and Mills have used a photometric method. From the micro-photometric record of the absorption spectrum the beginning of continuous absorption is traced, and the corresponding wavelength is known with the help of the comparison spectrum micro-photographed on the same plate. The accuracy of this method depends entirely on the sensitiveness of the micro-photometric record. It has been observed, however, that the recording instrument does not respond well to small changes of density of the photographic image, which is essential for accurate determination of the limit.

The method adopted in the present work is that due to Herzberg and Scheibe, later on employed by Datta, and one which appears to be less objectionable. Corresponding to a particular wavelength in the comparison spectrum micro-
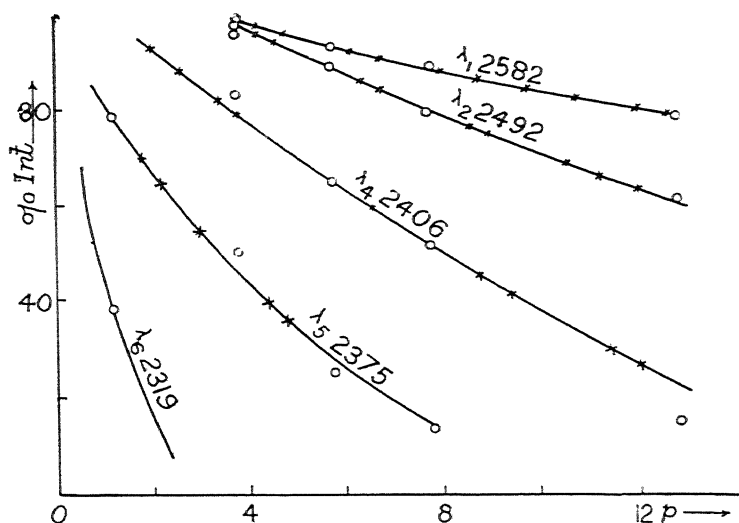


Fig. 3

photometric records are obtained for the regions in the absorption spectra of different pressures. Taking the intensity of the continuous spectrum as 100, the intensities corresponding to other pressures are calculated. A curve is then drawn with the pressure along the X-axis and intensity along the Y-axis, which becomes exponential in nature, the intensity falling off according to a relation $I = I_0 e^{-\alpha p}$ where $\alpha$ is the coefficient of extinction; $\alpha$ is calculated for different wavelengths of the spectrum $\lambda_1, \lambda_2, \lambda_3, \ldots$. A curve is then plotted with

wavelength as abscissa and the extinction coefficient as ordinates. On extrapolating this curve the wavelength corresponding to zero extinction coefficient is obtained, which must be the beginning of continuous absorption. The two sets of curves for $CCl_4$ and $CH_2Cl_2$ are shown in Figs. 3, 4, 5, 6.
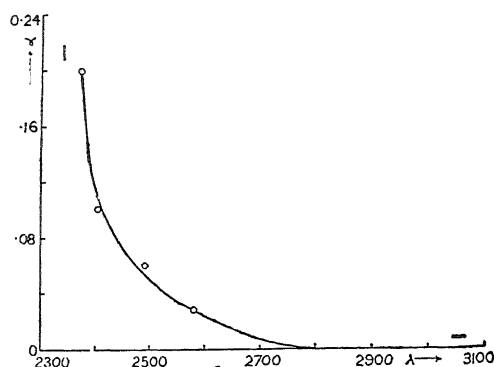


Fig. 4

One great advantage of this method over others is that it eliminates the uncertainty due to the arbitrariness of the gas pressure and length of the absorbing column.
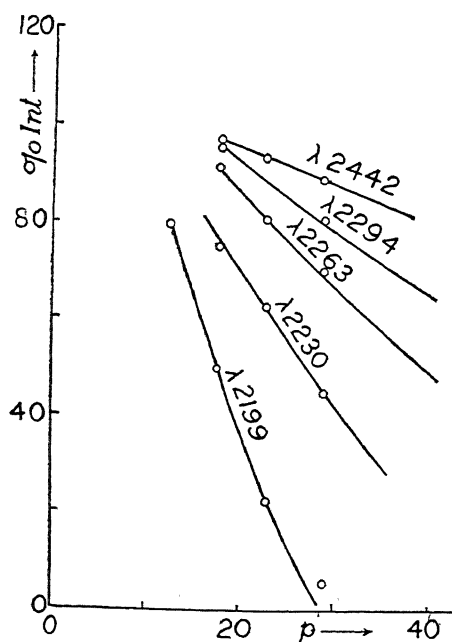


Fig. 5
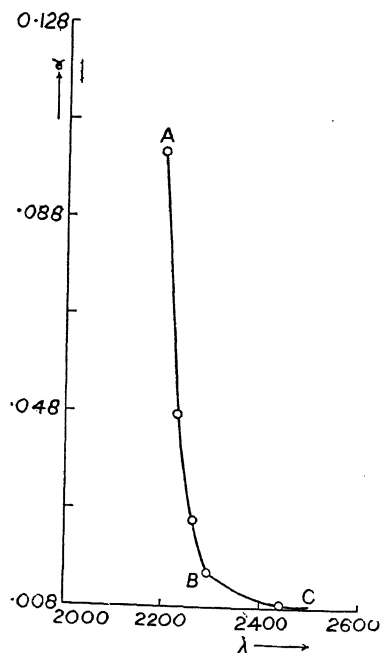


Fig. 6

The absorption limits obtained by this method are shown in the following table.

## TABLE 1

| Substance | λ in Å. U. limit | $Q_m = h\nu$ in k cal. for C—Cl bond. | $Q_m = h\nu$ in k cal. for C—H bond. |
|---|---|---|---|
| C Cl | 2800 | 102 | — |
| CH Cl$_3$ | 2660 | 107·5 | ? |
| CH$_2$ Cl$_2$ | 2500 | 114·4 | 124 |

The third column represents the molecular energy $Q_m$ corresponding to the beginning of absorption λ (limit) expressed in k cal. This is calculated according to the relation—

$$Q_m = \frac{Nh\nu_m}{J}$$

where N=Avogadro number and $\nu_m$ = the limiting frequency corresponding to λ (limit). This evidently denotes the energy of the bond in each case.

### Calculations from Thermo-chemical Data

The energy of the C—Cl bond can be calculated for each of the above compounds from its known heat of combustion and some other thermo-chemical data. Take the case of C Cl$_1$. Assuming the C atom in the formation of this molecule to exist in $^5S$-state, heat of sublimation of C from solid to $^3P$-state equal to 161 k cal. and the energy difference $C(^5S) - C(^3P) = 119$ k cal[*], we get—

$$[C]_{solid} = C(^3P) - 161 \text{ k cal.}$$

$$C(^3P) = C(^5S) - 119 \text{ k cal.}$$

$$\overline{[C] = C(^5S) - 280 \text{ k cal.}}$$

*i.e.*, the total heat of sublimation of C=280 k cal. Now heat of formation of $CO_2 = 94$ k cal.

[*] The heat of sublimation of C (in the $^3P$-state) is rather uncertain. The usually accepted value due to Kuhn and Guckel (*Zeits f. Physik*, 27, 305, 1924) is 139 kcal. while in a recent note published in the *Phys. Rev.* (41, 1932) a value ranging between 161 to 176 k cal has been given. Here we have taken the lower limit 161 k cal.

The energy of excitation $C(^5S) - C(^3P)$ is also equally uncertain. Heitler and Herzberg[10] from the considerations of the quantum mechanical theory of homopolar bonds estimated this energy to be 1·6 volts which is about 37 kcal. Iredale and Mills on the other hand assume that the C atom exists in CO$_2$ in the quintet state and in CO in the triplet state, and that the energy of binding of C in O=C=O is double that in C=O. Taking the heat of of sublimation of C to be 139 k cal, they calculated the energy of excitation from the triplet to the quintet state to be 97 k cal, *i.e.* about 4 volts. It is to be seen that the two values are widely divergent nor any of the two methods of calculation is based on solid grounds, though both of them admit that the triplet state is deeper than the quintet state. In this paper Iredale and Mills' method has been followed and using the heat of sublimation as 161 k cal the energy of excitation re-calculated is 119 k cal which is about 5 volts.
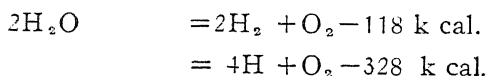
Heat of formation of H$_2$O refers to the vapour state. Other data have been taken from Landolt and Börnstein's tables.

Thus

$$CO_2 = [C] + O_2 - 94 \text{ k cal.}$$
$$= C(^5S) + O_2 - 374 \text{ k cal.}$$
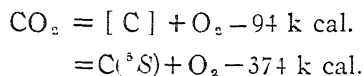
Heat of formation of $H_2O$ $= 59$ k cal.

Heat of dissociation of $H_2$ $= 105$ k cal.

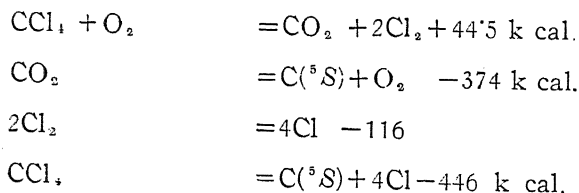$$2H_2O = 2H_2 + O_2 - 118 \text{ k cal.}$$
$$= 4H + O_2 - 328 \text{ k cal.}$$

Energy of the C-H bond $= 123$ k cal.

Heat of combustion of $CCl_4 = 44.5$ k cal.

Heat of dissociation of $Cl_2 = 58$ k cal.

Thus

$$CCl_4 + O_2 = CO_2 + 2Cl_2 + 44.5 \text{ k cal.}$$
$$CO_2 = C(^5S) + O_2 - 374 \text{ k cal.}$$
$$2Cl_2 = 4Cl - 116$$
$$CCl_4 = C(^5S) + 4Cl - 446 \text{ k cal.}$$

Assuming this energy to be equally distributed among the four carbon halogen bonds, the energy of the $C-Cl$ bond $= 111.5$ k cal.

Similarly using the heat of combustion of $CHCl_3 = 70$ k cal; we get

$$4CHCl_3 + 5O_2 = 4CO_2 + 2H_2O + 6Cl_2 + 280 \text{ k cal.}$$
$$4CO_2 = 4C(^5S) + 4O_2 - 1496$$
$$2H_2O = 4H + O_2 - 328$$
$$6Cl_2 = 12Cl - 348$$
$$CHCl_3 = C(^5S) + 3Cl - 473 \text{ k cal.}$$
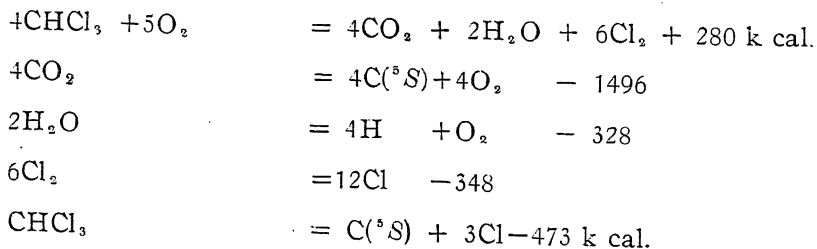
Subtracting $C-H$ bond energy $= 123$ k cal, $C-Cl$ bond energy comes out to be $116.5$ k cal.

In the same way for $CH_2Cl_2$ the energy of the $C-Cl$ bond is calculated to be $121.5$ k cal. using the heat of combustion for this compound as $106.8$ k cal.

The quantitative values calculated above are likely to be questioned when one considers the fundamental assumption made regarding the state of the carbon atom. The ground state of C atom according to its electronic structure is $2s^2 2p^2$. But it has been supposed that in the above compounds C exists

in $^5S$- state. The origin of such an assumption is a theoretical conclusion reached by Heitler and London on the chemical valency of elements, viz., the valency of an element in molecular formation is numerically equal to the multiplicity of the ground state of the element diminished by one. Since in $CH_4$ and its substituted halogen-derivatives C is regarded as tetravalent, the multiplicity of the ground state is supposed to be five. From spectroscopic point of view the $^5S$- state of the C atom may arise if the configurations of its 6 electrons be $1s^2 2s 2p^3$, instead of $1s^2 2s^2 2p^2$ as in the normal atom. The possibility for the existence of such a configuration of C atom in these compounds is doubtful and requires confirmation from other sources.

## Discussion of Results

The experimental results given in (table 1) definitely show that there is a regular shift of the beginning of absorption towards longer wavelength as we pass from one to the other compound of the series $CH_2Cl_2$, $CHCl_3$, $CCl_4$, by an amount very nearly equal to 150 Å.U. This is equivalent to the fact that assuming the strength of the C—H bond to remain constant throughout, the strength of the C—Cl bond diminishes as we gradually replace the H atoms of $CH_4$ by more and more Cl atoms. An inspection of the results calculated from thermochemical data exhibits a similar variation of the strength of the C—Cl bond. It may be objected, however, that the latter calculations have been based on the assumption that in a compound like $CH_n Cl_{4-n}$ the C atom exists in $^5S$- state. To this objection it may be answered that even though there is such uncertainty regarding the state of the C atom in these compounds, and consequently the heat of sublimation of C, this does not affect very much our conclusion regarding the *differences of bond energies*.

An examination of curve ABC (Fig. 7) for $CH_2Cl_2$ reveals a discontinuity at the point B. The discontinuity of the curve at this region seems to have special significance. The curve ABC may be looked upon as being composed of two curves $A_1BC$ and $A_2B'$ shown by dotted lines, superposed on each other. The curve is thus composite ; and the best way to explain this is to assume that here we have to deal with two photochemical processes, viz. (A) the photochemical disruption of the C—Cl bond beginning at $\lambda 2500$ and represented by curve (1), and (B) photochemical disruption of the C—H bond beginning at $\lambda 2290$, and represented by curve (2). According to this interpretation, the value of the C—H bond is 124 k cal. This result is in fair agreement with the commonly accepted value of C—H bond-energy as 123 k cal. It is remarkable that the absorption curve for $CCl_4$ does not represent any such discontinuity, there being only one type of energy bond, viz., C—Cl present in the molecule.

The absorption curve for $CHCl_3$ should also show similar discontinuity. Unfortunately the experimental curve obtained is not very conclusive. The

experiment, specially the microphotometric records are being repeated to decide this point
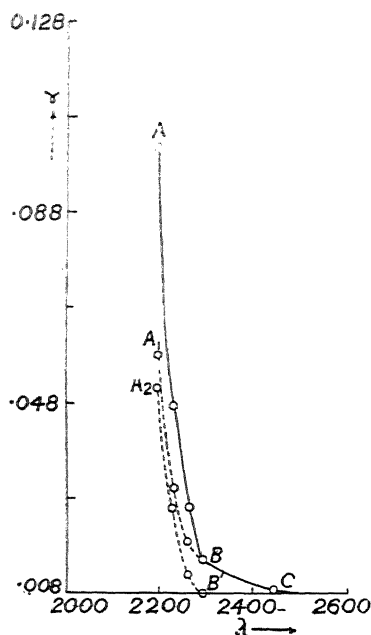


Fig. 7

The reason for the observed variation of C—Cl bond energy is not very clearly understood. It appears· reasonable to think that the interaction between Cl atoms, which increases with the increase of the number of Cl atoms, in the molecule, is responsible for the weakening of the bond strength, by setting up some sort of constraint of the carbonhalogen bonds.

A molecule of $CH_4$ is represented by symmetrical tetrahedral structure with the C atom at the centre. and the four H atoms at the four apices of a regular tetrahedron (Fig. 8). Such a structure is supported by (i) the study of the X-ray diffraction pattern of the crystal structure of a certain tetra-substituted derivatives of methane of the form C ( a )₄ by Nitta,[11] Schleede[12] and others, and (ii) by the absence of electric moment in $CH_4$ and a few of its tetra-substituted derivatives. We may then suppose that in $CH_4$ molecule four equal forces acting from the central carbon atom towards the four H atoms are producing an equilibrium Let us now think that the two of the H atoms are replaced by two Cl atoms, as in $CH_2 Cl_2$. For such a molecule the structural model will evidently be a distorted tetrahedron, the distorsion being brought about mainly by two causes :—(1) the forces acting from the C atom towards the apices being unequal

the position of the carbon atom will be shifted from the centre of the tetrahedron ; (2) the radius of the sphere of collision of a Cl atom is much larger than that of a H atom. Assuming two H atoms in $CH_4$ to be separated by a distance not much
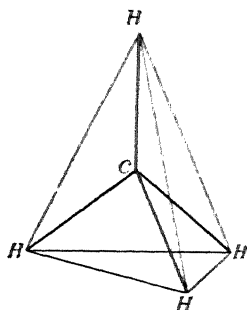


Fig. 8

greater than the diameter of the sphere of collision of an H atom, as soon as the two H atoms are replaced by two Cl atoms, the angle between the two C—Cl bonds must widen so that the two Cl atoms may remain uncompressed. So gradually by increasing the number of Cl atoms in the molecule, the amount of distortion relative to the symmetrical structure will more and more increase, as the conditions in both the factors (1) and (2) will be changed. Therefore, compared to one compound of the series, say $CH_2Cl_2$, the constraints in the bonds of the next compound $CHCl_3$ will have a change which will alter the strength of the carbonhalogen bond.

The variation of the dipolemoment[13] of compounds of the series $CH_4$, $CH_3Cl$, $CH_2Cl_2$, $CHCl_3$, $CCl_4$ from one to the other member is well known. The amount of variation cannot be explained on the simple basis of the substitution of a Cl atom for a H atom in the symmetrical tetrahedral model. The distortion of the tetrahedron due to the two causes must be taken into account. The effect due to the cause (2) is very uncertain, and it seems, no proper allowance has been made for it in theoretical calculations. We may suppose that this effect is equivalent to an alteration of the C—Cl bond strength as obtained from the study of their continuous absorption spectrum. Thus, if proper allowance is made for the variation of the C—Cl bond energy in the successive compounds, the effect due to the second cause becomes practically incorporated in that due to the first. The latter can be calculated from the geometry of the regular tetrahedron and the statical conditions of equilibrium of forces. So a fresh calculation of the electric moments of these compounds may be attempted on this basis. It must be confessed that the accuracy of the absorption data is not at present very great. But still an approximate result can at any rate be expected.

In conclusion I wish to express my sincere thanks to Prof. M. N. Saha, F.R.S. for his kind guidance and valuable suggestions throughout the progress of the work.
F. 6

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# ON THE ABSORPTION SPECTRA OF THE OXIDES OF ZINC AND CADMIUM

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## Introduction

The following experiments were undertaken with a view to extending Franck's theory of action of light on saturated chemical compounds. The group chosen in these series consist of oxides and sulphides of a simple form. Experiments on $SO_2$, $N_2O_5$, $TeO_3$, and $MoO_3$ by A. K. Datta and the present author[1] have already been reported. In the present communication the results of experiments with saturated monoxides, *viz.*, ZnO and CdO are reported. HgO was also tried, but this substance readily decomposes before any appreciable vapour is available, and no positive results were obtained.

## Experiment

Since the oxides of Zinc and Cadmium begin to vaporise at rather high temperatures (from about 1000°C and 800°C respectively), the vacuum graphite furnace of this laboratory was utilised. The oxides were introduced in silica tubes 20 cms. long into the furnace. The source of continuous spectrum was a Hydrogen tube run by a 2 KW. transformer, and the photographs were taken on an E₄ quartz spectrograph. Exposures of 2 to 4 minutes were sufficient. The copper arc was used for comparison.

## Results

Two sets of experiments were undertaken, one with varying temperatures in vacuum and the other under similar conditions with air inside the absorption chamber. Air served only to prevent the distillation of the vapours, as well as to introduce a small quantity of Oxygen into the absorption chamber. Pure Oxygen under atmospheric pressure could be used, but the presence of the large quantity of Oxygen causes the graphite tubes to burn away in no time at the high temperatures used, making observation almost impossible.

CdO—*Experiments in vacuum.*—The vacuum was of the order of 1 to 2 mms. and the pump was kept running continuously throughout. Light was found to be cut off in the ultra-violet from a long wave limit about 2150 A°. The continuous absorption was rather extended on account of the low pressure of CdO vapour. Higher temperatures revealed some bands in some of the plates. The following is a list of some of them.

| | |
|---|---|
| 2107 | 2067 |
| 2099 | 2047 |
| 2086 | 2026 |
| 2076 | |

These bands could easily be identified with those of CO[2]

Now at high temperature of the order of 1200°C CdO decomposes into Cd and $O_2$ with the result that the resonance line 2288 ($1s-2p$) was obtained in absorption. But at the same time the graphite of the furnace tube vaporises and forms with the liberated Oxygen, CO and $CO_2$.

CdO.—*Experiments in Air.*—When the furnace is filled with air and pump is not run we can expect thermodynamical equilibrium to hold good. We have then

$$\frac{P_{Cd}}{P_{CdO}} = \sqrt{\frac{K}{P_{O_2}}} = \text{constant}$$

Since the value of K rapidly increases with T, and $P_{O_2}$ is almost constant and $P_{CdO}$ is given by the saturated vapour pressure of CdO, $P_{Cd}$ would increase very rapidly with temperature.

This circumstance explains the results. The absorption of the resonance line $^1S-^1P$ becomes very broad and the intercombination line $\lambda$ 3267 ($^1S-^3P$) now becomes discernible showing that we have much more Cd-vapour now in the absorption vessel. It is also clear from the appearance of $Cd_2$ bands which were first discussed by Winans. These are highly developed as T increases, and their breadth reaches the enormous extent of 160-Å units nearly. Besides the 2288 band the 2212 band recorded by Winans was obtained and also a line at 2136 which is easily identified with the resonance line of Zinc probably occurring as an impurity in the CdO.

The continuous absorption by the Oxide was very prominent under these conditions (high temperatures, tube filled with air) as CdO-gas has now chances of reaching the equilibrium value. The cut off is found to begin from 2100 A units.

ZnO.—The behaviour of Zinc Oxide is similar to that of Cadmium Oxide. In vacuum the CO-bands were obtained, and the absorption by the Oxide was not very well defined. In the presence of air, the asymmetric broadening of the resonance line 2136 of Zinc due to the formation of $Zn_2$ molecule was present along with band absorptions of $Zn_2$—molecule. The absorption by the Oxide was better defined

and obtained at 2000A°   The intercombination Zinc resonance line  $S - {}^1P$ was not obtained in absorption.   This is probably due to the comparative faintness of this line compared with that of Cadmium.

It might be mentioned here that in the absorption of both ZnO and CdO in air at very high temperatures some of the long wave members CO bands were obtained.

## Calculations

From theoretical considerations

$$CdO + R = Cd + O$$

and

$$R = Nh\nu_1/J$$

where R can be determined with the aid of the following relations

$$[CdO] + L_{CdO} = CdO$$

$$[Cd] + L_{Cd} = Cd$$

$$O_2 + D_{O_2} = 2O$$

$$[CdO] + Q = [Cd] + \tfrac{1}{2}O_2$$

$$\therefore \quad R = Q + \tfrac{1}{2}D_{O_2} + (L_{Cd} - L_{CdO})$$

in which

$Q$    = Heat of formation of [CdO] from [Cd] and $O_2$

$L_{Cd}$  = Latent heat of sublimation of Cd

$L_{CdO}$  = Latent heat of sublimation of CdO

$D_{O_2}$  = Heat of dissociation of $O_2$

Out of these $Q$ and $L_{Cd}$ can be found in Landolt and Bornstein's tables. $D_{O_2}$ has been estimated by Datta[1] to be 128 k cals and by Herzberg to be 117 k cals. But $L_{CdO}$ is unknown, and it has been roughly estimated with the help of Trouton's rule as follows:—

$$\frac{L_{CdO}}{T} = 23 \text{ where T is the boiling point at the absolute}$$

temperature.

$$\therefore \quad L_{CdO} = 23 (1000 + 273)$$

$$= 29\cdot2 \text{ k cals nearly.}$$

$$\therefore \quad R = 63 + 64 + (26 - 29\cdot2)$$

$$= 124 \text{ k cals nearly.}$$

Experimentally the limit of absorption comes out to be 2100Å, which is equivalent to 135 k cals

**ZnO :** –

$$R = Q + \tfrac{1}{2} D_{O_2} + ( L_{Zn} - L_{ZnO} )$$
$$= 55 + 64 + (31.5 - 47)$$
$$= 154 \text{ k cals nearly.}$$

Experimentally $h\nu = 145$ k cals.

In both the cases the experimental value is slightly higher than the calculated value which is usually expected  In view of the fact that the estimation of the latent heats of ZnO and CdO are only rough, the agreements seem to be quite fair.

### Discussion

It is clear from the description of the behaviours of these oxides given in Mellor's Inorganic Chemistry that these substances not only give vapour at the temperatures of the order of $1200° - 1600°C$, but CdO (say) vapour is partially decomposed into Cd and $O_2$.  This enables us to understand the experimental results given above.

As mentioned before (according to the law of mass action as worked out for me by Mr. Ram Niwas Rai)

$$\frac{P^2_{Cd} \; P_{O_2}}{P^2_{CdO}} = K$$

*or*
$$P_{Cd}/P_{CdO} = \sqrt{\frac{K}{P_{O_2}}}$$

The value of the reaction isochore cannot be calculated as most of the constants required for this purpose on the right-hand side are unknown.  But it can be easily seen that when the pump is constantly run equilibrium conditions cannot be reached as there is constant flow of vapours to the cooler sides.  Now Cd and CdO are deposited on the cooler parts as solids and $O_2$ is pumped off.  Hence under these conditions neither $P_{Cd}$ nor $P_{CdO}$ can reach very high values.  This is clear from the absorption experiments.  Absorption of the resonance line 2288 ($^1S-^1P$) is readily obtained, but it never becomes very broad, as in the second set of experiments.  As already mentioned this broadening has been attributed by Winans to the formation of $Cd_2$ molecule which is only possible when the pressure of Cd vapour reaches above 10 mms  The order of the pressure being less than 10 mms. in the first set of experiments Winans' bands were not obtained.  The appearance of the Carbon Monoxide bands has already been explained.

The absorption of the intercombination line 3267 ($^1S-^3P$) is not discernible in the first set though it is prominent in the second one

The spectrum is continuously cut off from 2100 Å which we may safely ascribe to absorption by CdO vapour.  In the case of ZnO this is 2000 Å units.

## Conclusion

From the appearance of the continuous spectrum at the end of the spectrum it is concluded that the products of photochemical dissociation are two free atoms. In terms of potential energy curves this process is always represented by a curve of the form of $\beta$ (Fig. 1). The stability of the oxides gives rise to the deep minimum of the ground state $a$. By the transition AB due to the absorption of a quantum $h\nu$, of light the molecule comes to B in accordance with Franck-Condon principle and simultaneously dissociation occurs. (It might be mentioned here that the maximum value of AB is given by taking A in the minimum point of the ground state, or the lowest vibration state in which the molecule exists normally. As the temperature is raised, higher vibrational states are excited so that the value of AB diminishes. For this reason in calculations, $h\nu_1$ corresponding to the lowest temperatures has been used to get the maximum value of AB.
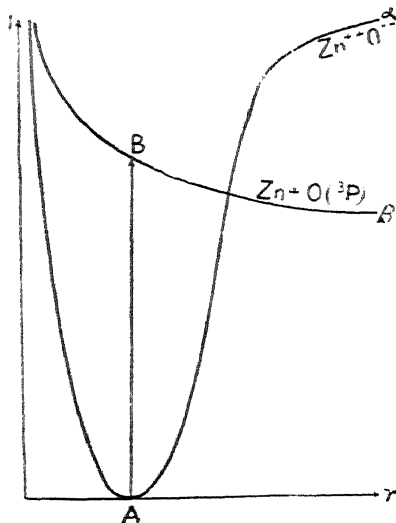


Fig. 1.

Now to account for the state $a$, we must assume that the force of attraction is either of electrostatic origin if the compound is ionic, or it is due to "austausch" forces if it is atomic. Since the upper state is atomic the lower state is expected to be ionic. But even then there are two possibilities —

(a) The constituents are $Zn^+$ and $O^-$.

(b) The constituents are $Zn^{++}$ and $O^{--}$.

In case (a), one electron passes from $O^-$ to $Zn^+$; in case (b), both the electrons of $O^{--}$ pass *simultaneously* due to absorption of light to the $Zn^{++}$-ion, giving rise to Zn and O. It will be shown that the second case is more probable, for in case (b) both $Zn^{++}$ and $O^{--}$ are diamagnetic, and ZnO will be diamagnetic as is actually found. If the constitution is $Zn^+ O^-$, the compound ZnO will be para-magnetic. A consideration of the binding energies according to the Born cycle bear out the same deduction. This is shown below.

Notation :

$I_{Zn^{++}}$ = Sum of the ionisation potentials of Zn and $Zn^+$.

## BORN-CYCLE FOR ZnO
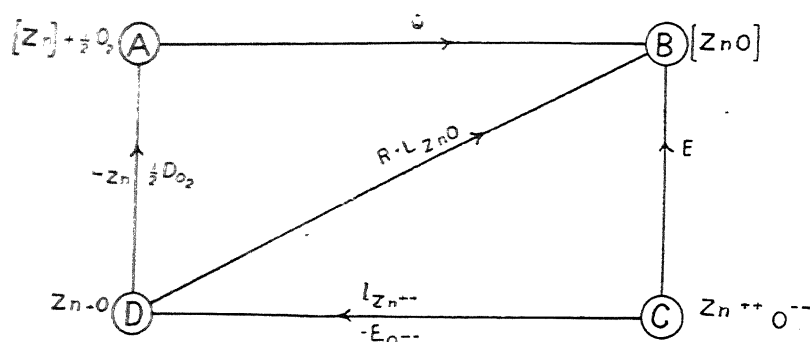


Fig. 2.

$E_O$ $^{--}$ = Heat of formation of an O -ion out of O and 2 electrons.

$E$ = Lattice energy, assuming that the units are $Zn^{++}$ and $O^{--}$.

Other quantities have their usual meanings.

We obtain from the diagram

$$E = Q + I_{Zn++} + L_{Zn} + \tfrac{1}{2} D_{O_2} - E_{O--}$$
$$= 85\cdot4 + 628 + 31\cdot3 + 64 - (-49)$$
$$= 857\cdot7 \text{ k cal.}$$

Senftleben[4] has given the electron affinity of $O^-$ as $-41\cdot4$ k cal taking into account the values of $D_{H_2}$ and $D_{O_2}$ as 80 and 175 k cal, respectively. These values have been replaced by more recent values 95 and $128'$ k cal respectively in the calculations of Senftleben and the result comes out to be $-49$ k cal for the value of $E_{O--}$, instead of $+1\cdot7$ k cal.

Now

$$R + L_{ZnO} = E - I_{Zn++} + E_{O--}$$
$$= 857\cdot7 - 628 - 49$$
$$\therefore \qquad R = (857\cdot7 - 628 - 49) - 47$$
$$= 133 \text{ k cal.}$$

This value of R could also be calculated with the aid of Born and Heisenberg's formula for the crystal lattice energy. As quoted by Born and Gerlach[5] for ZnS

$$E = K \frac{n-1}{n} \sqrt[3]{\frac{\rho}{M}}$$
$$= 2690 \cdot \frac{n-1}{n} \sqrt[3]{\frac{\rho}{M}}$$

where    K = a constant involving Madelung's coefficient,

   $n$ = the repulsion exponent,

   $\rho$ = the density,

   M = the molecular weight

Here $n$ is given by the formula

$$n = 1 + C \times \frac{1}{X} \cdot \left( \frac{M}{\rho} \right)^{\frac{4}{3}}$$

where X the compressibility = $77 \times 10^{-12}$ for ZnO. Since the crystal structures of ZnO and ZnS are similar, that is of the tetrahedron type, the values of K and C will be the same.

   For ZnO

$$n = 1 + 8\cdot00 \times 10^{-14} \cdot \frac{1}{X} \cdot \left( \frac{M}{\rho} \right)^{\frac{4}{3}}$$

$$= 1 + \frac{8\cdot00 \times 10^{-14}}{77 \times 10^{-12}} \left( \frac{81\cdot37}{5\cdot6} \right)^{\frac{4}{3}}$$

$$\therefore \qquad = 4\cdot64$$

and

$$E = 2690 \times \frac{3\cdot64}{4\cdot64} \times \sqrt[3]{\frac{5\cdot6}{81\cdot37}}$$

$$= 865\cdot4 \text{ k cal.}$$

From the triangle BCD of the Born cycle

$$R = 865\cdot4 - I_{Zn++} + E_{O--} - L_{ZnO}$$

$$= 141\cdot4 \text{ k cal.}$$

From experiment $R = \dfrac{Nh\nu_1}{J}$ comes out to be 143 k cal. The agreement seems to be quite fair.

   CdO.—Since Cadmium Oxide forms cubical lattices like that of NaCl or CaO we have

$$n^* = 1 + \frac{8\cdot80 \times 10^{-14}}{\cdot75 \times 10^{-12}} \cdot \left( \frac{128\cdot4}{8\cdot18} \right)^{\frac{4}{3}}$$

$$= 5\cdot61$$

and    $$E = 2450 \times \frac{n-1}{n} \sqrt[3]{\frac{\rho}{M}}$$

$$= 804\cdot6 \text{ k cal.}$$

$$R = 804\cdot6 - I_{Cd++} + E_{O--} - L_{CdO}$$

$$= 128\cdot6 \text{ k cal.}$$

Experimentally R = 135 k cal. There is a difference of about 7 k cal between the calculated and experimental values, which is quite within limits of error.

   * The value of X not being known, a mean value of $\cdot75 \times 10^{-12}$ from CaO and MgO and ZnO has been taken.

F. 7

The excretory system is as in *H. mehransis* with the difference that in this form the excretory pore lies subterminally on the ventral surface.

Of all the species of the genus *Halipegus spindale* bears a close relationship to *H. mehransis* in the form of the body, position of gonads and vitellaria, the relations of the female genital ducts and in the structure of the end apparatus of the reproductive organs. It differs, however, in the following important features which mark it out as a new species: the position and size ratio of the suckers, the presence of an oesophagus, the more or less straight and uniform breadth of the intestinal caeca ending in front of the vitellaria and the subterminal position of the excretory opening.

## Systematic discussion on the genus Halipegus Looss 1899 with remarks on the family Halipegidae Poche 1925, and the genus Vitellotrema Guberlet 1928.

The systematic position of the genus *Halipegus* has been much debated upon by various workers. Looss, who created the genus in 1899, assigned it a place near the *Syncoeliinae*. Lühe in 1901 included it in the family *Hemiuridae*. Ward and Whipple in 1918 and Nicoll in 1926 placed it in the category of unclassified genera. Dollfus in 1923 and Viana in 1924 assigned it to the *Syncoeliinae*. In 1925 Poche, however, created for it a new family *Halipegidae* which he included in his superfamily *Hemiuroidea*. Guberlet in 1928 and Faust 1930 following Poche have maintained the family *Halipegidae*. Odhner in 1927 created a new subfamily *Derogenetinae* under the family *Hemiuridae*, for the genera *Halipegus*, *Derogenes*, *Gonocerca* and *Lecithophyllum* which he considered to be closely related. Fuhrmann in 1928 follows Odhner in assigning the genus *Halipegus* to the *Derogenetinae*.

The genera *Halipegus* and *Derogenes* are closely related on account of the marked similarity in the general body-form, position and size of suckers, length of the intestinal caeca, topography of the gonads and the vitellaria, position of genital pore, large size of eggs with a polar filament at the posterior end and in the excretory system. The only points of difference between the two genera are in the position and arrangement of uterine coils and the extent of the prostate glands—characters which can at the most be considered of generic importance. I, therefore, drop the family *Halipegidae* Poche 1925 and include the genus *Halipegus* in the *Derogenetinae*.

The genus *Vitellotrema* as included in the family *Halipegidae* by Guberlet differs from the type genus of the family only in the unlobed character of the vitelline glands. There is one species of *Halipegus*, i.e., *H. kessleri* syn. *H. rossicus* which has got unlobed vitelline glands like those of the genus *Vitellotrema*. It seems that Guberlet was not aware of the latter condition, as appears from the list of references given in his paper, otherwise he would not have thought of creating his new genus on the basis of this character.

The lobed or unlobed character of the vitelline glands, as discussed by Looss in 1901 and Manter in 1926, should not be considered to be of generic importance even in cases where the lobes are distinctly separated into closely aggregated follicles. This view is also supported by the condition of the vitelline glands in the new species of Progonus Looss and of *Ophiocorchis* n. gen. which are described by me in this paper. These species resemble each other closely in most features except in the lobed or unlobed character of the vitellaria. I, accordingly, drop the genus *Vitellotrema* and refer its type species to the genus *Halipegus*.

The diagnosis of the genus *Halipegus* as now constituted is as follows :- -

*Derogenetinae:* with a highly muscular and smooth, usually cylindrical rarely flattened body. The suckers are well developed and muscular; the acetabulum larger than the oral sucker, situated about or in the middle of the body. Muscular pharynx present; oesophagus present or absent, intestinal caeca long extending either up to the extreme hinder end or stopping in front of the vitelline glands. The excretory bladder is Y-shaped with a long median stem and two long cornua which run forwards and unite together in the region of the oral sucker or the pharynx. The genital pore is situated either in the region of the pharynx or distinctly behind the intestinal bifurcation ; a small genital atrium is present. A ductus hermaphroditicus may be absent or present. The testes two in number, situated symmetrically or asymmetrically in the first half of the post-acetabular region ; a small vesicula seminalis and a slight pars prostatica are present but a cirrus is absent. The rounded ovary is situated near the hinder end of the body in front of the vitellaria. The vitellaria lie in two lobed or unlobed groups placed symmetrically or obliquely behind the ovary at the hinder end of the body. Receptaculum seminis is absent. Laurer's canal is present. The long uterus consists of only ascending part in transverse coils containing a huge number of large-sized eggs bearing a long or short polar filament at their posterior end. Parasitic in the mouth cavity, eustachian tubes, pharynx, stomach and intestine of fishes, frogs and snakes.

### Key to the species of the genus Halipegus Looss.

Vitelline glands lobed                 A
Vitelline glands unlobed            B
  A. Testes situated far behind the acetabulum, close to
       the ovary   .   .   .   .   .   .   . *H. ovocaudatum*
       Testes situated close behind the acetabulum, far
       in front of the ovary   .   .   .   .   . 1
    1. Oesophagus present           2
       Oesophagus absent          3

F. 7

2. Intestinal caeca extend up to the extreme posterior
    end and the excretory pore terminal . . *H. occidualis*
   Intestinal caeca end in front of the vitellaria,
    excretory pore subterminal . . . . *H. spindale* n. sp.

3. Genital pore lies in the region of the pharynx,
    the uterine coils do not overlap the intestinal
    caeca anteriorly in front of the testes . . *H. longispina*
   Genital pore situated behind the intestinal bifurca-
    tion; uterine convolutions extend to the body-
    wall both in front and behind the acetabulum . 4

4. Size 3·1—5·1 mm; acetabulum situated in the
    middle of the body 1·8 times the size of the
    oral sucker . . . . . . . . *H. mehransis* n. sp.
   Size 1·9—1·9 mm; acetabulum situated between
    first 1/3 and 1/2 of the body and twice the size of
    the oral sucker . . . . . . . *H. mehransis var*
                                       *minutum* n. var.

B. Intestinal caeca reach behind the vitellaria up to
    the extreme hinder end of the body . . . *H. fusipora.*
   Intestinal caeca stop in front of the vitellaria . . *H. kessleri.*

### Genus *Progonus* Looss 1899 (=Genarches)

The only hitherto known species of this genus was described by Levinsen in 1881, for which Looss in 1899 created the genus *Progonus,* assigning it to the *Syncoeliinae* Looss. Luhe founded the family *Hemiuridae* in 1901 and included in it the genus *Derogenes* along with the genera with tail appendage. Looss in 1907 limited the scope of the family and retained under it only such forms as possess a tail appendage. Odhner in 1911 pointed out that *Derogenes* is so closely related to the other *Hemiuridae* that its separation from the family is impossible and that the genus *Progonus* which is closely related to *Derogenes* should be included in the *Hemiuridae.* Nicoll in 1913 agreed with Odhner in this view reducing the family *Hemiuridae* Looss to the position of a subfamily. Ozaki in 1925 described a new genus *Genarchopsis* a form closely resembling *Genarches mulleri* (Levins) and assigned it to the subfamily *Syncoeliinae.* Odhner in 1927 pointed out that *Progonus* shows a close rela-tionship with *Derogenes* in most of its characters and consequently he included it with *Derogenes* in a new subfamily *Derogenetinae.* The only feature in which *Progonus* differs from *Derogenes* is the presence of a caudal anastomosis of the intestinal caeca near the hinder end of the body, which Odhner con-siders to be an example of "convergence". In the following year Fuhrmann following Odhner included the genera *Derogenes, Genarchopsis, Gonocerca, Licithophyllum, Bunocotyle,* and *Halipegus* in the subfamily *Derogenetinae.*

The systematic discussion at the end of the description of the new species of *Progonus* in this paper will show that the genus *Genarchopsis* Ozaki 1925 is identical with *Progonus* and that *P. ovocaudatum* is an intermediate species between the two synonymous genera.

## Progonus piscicola n. sp.

(Fig 4)

Host—*Ophiocephalus punctatus*.
Habitat— Stomach.
Locality—Allahabad.

Three specimens of this trematode were obtained from the stomach of one out of about a dozen fish examined in June 1932. In the living condition the parasites are light brown in colour and show great power of contraction and expansion. The body is muscular and somewhat cylindrical in form with a broadly rounded off anterior and a pointed posterior end. The distomes are of moderate size measuring 3·3—3·4 mm in size and 1·12 in maximum breadth which is attained about the middle of the body. The body in front of the acetabulum is uniformly broad while the post-acetabular portion tapers sharply to the posterior pointed end. The well-developed and muscular suckers have a circular outline. The oral sucker measuring 0·33—0·34 mm in diameter lies subterminally at the anterior end of the body, with its cavity directed towards the ventral surface. The acetabulum of 0·66—0·68 mm diameter is twice as large as the oral sucker, situated in the first half of the post-equatorial region.

The oral sucker opens posteriorly into a spherical thick-walled pharynx of 0·12—0·14 mm diameter. In the absence of an oesophagus the intestinal bifurcation takes place directly behind the pharynx at a distance of 0·48—0·53 mm from the anterior end. The intestinal caeca have a highly crenated outline and run at first transversely and then turning downwards continue in a wavy course up to the hinder end of the body where they are continuous into each other just in front of the vitellaria.

The excretory bladder is Y-shaped consisting of an unbranched median stem which bifurcates just behind the acetabulum into two long cornua extending laterally right up to the level of the pharynx and uniting with each other on the dorsal side of the latter. The excretory bladder opens terminally at the hinder end of the body. The terminal part of the bladder is surrounded by a sphincter formed by a group of deeply staining parenchymatous cells with prominent nuclei.

The semilunar slit-like genital pore is sinistral or median, situated ventrally in level with the pharynx. It leads into a roomy genital atrium of

0'13—0'15 mm depth within which projects a highly contractile nipple-shaped genital cone or papilla. Both the genital atrium and the papilla are lined with cuticle. On the tip of the genital papilla opens the short common genital duct which may be termed as the ductus hermaphroditicus.

The testes are extracaecal and ovoid in form, situated a little obliquely behind the acetabulum, one on each side between the intestinal caeca and the bodywall. The left testis, 0'16—0'22 × 0'17 mm in size, lies slightly nearer the acetabulum than the right testis which measures 0'17—0'19 × 0'16—0'22 mm in size. The vesicula seminalis consists of an elongated coiled tube filled with sperms lying free in the parenchyma. Anteriorly it is continued into a short ductus ejaculatorius which opens in the terminal part of the uterus forming a short ductus hermaphroditicus. A few prostate gland cells surround the ductus ejaculatorius.

The ovary is an oval structure of 0'14—0'2 × 0'17—0'19 mm size, situated intracaecally to the right of the median line close behind the right testis. The shell gland complex, measuring 0'14—0'19 × 0'16—0'17 mm in size, is a prominent compact structure lying in contact with the posterior margin of the ovary. The vitellaria consists of two large compact glands situated asymmetrically in the extreme hinder part of the body behind the intestinal arc. The right vitelline gland 0'16—0'17 × 0'16 mm in size, lies obliquely behind the left gland of 0'2—0'25 × 0'15 mm size. The vitelline ducts of each side join together to form a short common duct which opens into the oviduct. A Laurer's canal is present but a receptaculum seminis is absent. The relations of the female genital ducts are shown in figure 9. The uterus lies in thickly crowded ascending coils which extend on the sides up to the bodywall. The initial part of the uterus is filled with sperms and may be regarded as the receptaculum seminis uterinum. Posteriorly the uterine convolutions do not extend beyond the shell gland complex. The terminal part of the uterus receives the ductus ejaculatorius forming a short ductus hermaphroditicus which opens on the genital papilla. A metraterm is absent. The numerous golden yellow eggs are fairly large measuring 0'048 × 0'015 mm in size and bearing a polar filament of 0'04 mm length at its posterior end.

In its affinities *Progonus piscicola* n. sp. stands nearest to *P. goppo* owing to the close similarity in the general shape of body with smooth cuticle, the size of the acetabulum, absence of a prepharynx and oesophagus, oblique position of the testes, compact nature of the two vitelline glands, absence of a receptaculum seminis and the uterine convolutions being confined anterior to the vitellaria. The important points of differences are: the larger size of body, distinctly caudad position of the acetabulum, size ratio of the suckers, position of the genital pore, topography of the gonads, asymmetrical position of the vitellaria, the arrangement and extent of the uterine coils which extend up to the bodywall on either side.

## Progonus ovocaudatum n. sp.

(Fig. 5)

Host—*Ophiocephalus punctatus*.

Habitat—Intestine.

Locality—Allahabad.

Only two specimens of this species were obtained from the intestine of one out of about thirty fish examined by me in the winter months of 1932. The parasites have a smooth and muscular body, somewhat cylindrical in form with broadly rounded off ends. They may at times present a slightly ringed appearance in the contracted condition. In entire mounts the distomes measure 1·5—2·3 mm in length and 0·5—0·8 mm in maximum breadth which occurs in the preacetabular region. The suckers are well developed, spherical and muscular. The subterminal and ventrally directed oral sucker measuring 0·048—0·064 mm in diameter is half the size of the ventral sucker which measures 0·096—0·12 mm in diameter. The ventral sucker is situated in the middle of the body with its major portion lying caudad of the body centre. The genital pore lies near the median line just behind the intestinal bifurcation. The genital atrium is about 0·07 mm deep and encloses a small contractile papilla. The excretory system is as in other species of the genus.

The mouth leads posteriorly into a muscular pharynx of 0·01 mm diameter. An oesophagus is absent. The intestinal caeca have a broad and wavy outline with marked constrictions along its course and are continuous at the posterior end in front of the vitellaria.

The testes are somewhat triangular in outline, lying a little asymmetrically, one on either side about the middle of the post-acetabular region. The left testis, measuring 0·1—0·16×0·13—0·17 mm in size, is slightly larger than the right one which is 0·14—0·16×0·13—0·19 mm in size. The vesicular seminalis is a curved tube of 0·4×0·05 mm size lying in two turns to the right side of the median line. It opens into the terminal part of the uterus through a small ductus ejaculatorius which is surrounded by prostate gland cells.

The ovary lies close behind the left testis. It is a spherical structure of 0·1—0·17 mm diameter. The shell gland complex, 0·05 mm in diameter, is situated in the median line behind the ovary just in front of the intestinal arc. A Laurer's canal is present but a receptaculum seminis is absent.

The uterus is well developed and lies in transverse convolutions which extend at a few places beyond the intestinal caeca on either side. Posteriorly the uterine coils extend between the vitelline glands up to the hinder end of the body. The terminal part of the uterus is as in *P. piscicola*. The uterus is packed with numerous small golden yellow eggs of 0·037×0·017 mm size, bearing a small polar filament at its hinder end

The vitellaria consist of two compact, symmetrically situated glands, one on either side in the posterior end and behind the intestinal anastomosis. The

The foregoing shows that these oxides are ionic in compounds of the type $Zn^{++}O^{--}$. By the action of light both the electrons from $O^{--}$ are simultaneously transferred to $Zn^{++}$ with result that two normal atoms Zn and O ($^3P$) are obtained, the linkage being broken.

In Fig. 1, the state α represents $Zn^{++}O^{--}$ and the state β, two normal and free atoms Zn and O($^3P$). There are two metastable states of Oxygen, $^1D_2$ and $^1S_0$, so that a second absorption after a retransmitted patch of light is possible for $^1D_2$ state in accordance with the process (2)

$$ZnO + h\nu_1 = Zn + O(^3P) \qquad \dots \qquad \dots \qquad \dots \qquad (1)$$

$$ZnO + h\nu_2 = Zn + O(^1D_2) \qquad \dots \qquad \dots \qquad \dots \qquad (2)$$

and similarly a third one for $^1S_0$. Thus $h\nu_1 - h\nu_2$ from experiment should be equal to $^3P - {}^1D_2$ of oxygen, as was found to be the case by Datta and the present author for the higher Oxides. These absorption cuts are expected in the fluorite region for ZnO and CdO, and it is not possible that they can be demonstrated.



Fig. 3.

The other alternative for the photochemical process, viz.,

$$Zn^{++}O^{--} + h\nu = Zn^{+} + O^{-} \qquad \dots \quad (1a)$$
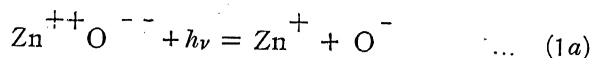
that is, the product of photochemical dissociation are not two normal atoms but a singly ionised Zinc and a negative Oxygen ion singly charged, appears to be excluded for the following reasons. It is evident that the electrostatic force is not completely destroyed and the potential energy curve for $Zn^{+}O^{-}$ will be shown in B with a minimum. A photochemical process leading to such a transition as AB will be manifested as a band absorption. Up to this time, no trace of such absorption has been obtained.

My best thanks are due to Prof. M. N Saha, D.Sc., F.R.S., for taking kind interest and rendering valuable guidance during the course of the work.

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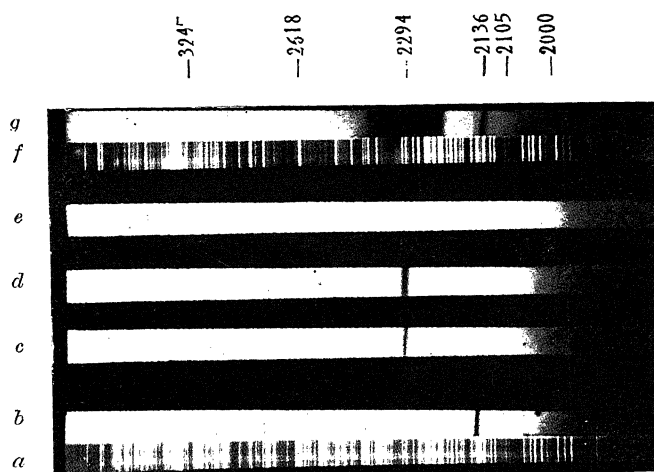
a, f    ... Copper arc spectra.
e       ... Continuous spectrum.
b       ... Absorption spectrum of ZnO (in air).
c, d    ... Absorption spectra of CdO (in air).
g       ... Absorption spectrum of CdO (in air) at very high temperature showing the absorption of Cd$_2$ molecule.

# COLOUR AND CHEMICAL CONSTITUTION:
## THE EFFECT OF AUXOCHROMIC GROUPS ON PHTHALOPHENONE NUCLEUS.

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Received March 21, 1933.

In a previous paper[1] by the present author fluoresceins and rhodamines of the mixed type were prepared by condensing 2:4-dihydroxy-benzoyl-benzoic acid with aromatic hydroxy and amino-hydroxy compounds, and the interesting derivatives of fluoran that were thus obtained were examined spectroscopically in order to arrive at a generalisation with respect to colour and constitution of these substances. It was found from a systematic examination of the absorption spectra of these compounds that the nearer a hydroxy or an amino group is to the pyrone oxygen atom of the molecule the greater is the intensity of the colour of the substance.

In the present paper the author has tried to study the problem from a slightly different point of view. Instead of preparing derivatives of fluoran as in the previous paper, hydroxy and amino-hydroxy derivatives of phthalophenone have been prepared by condensing $p$-hydroxy-benzoyl-benzoic acid with aromatic hydroxy and amino-hydroxy compounds thus :—
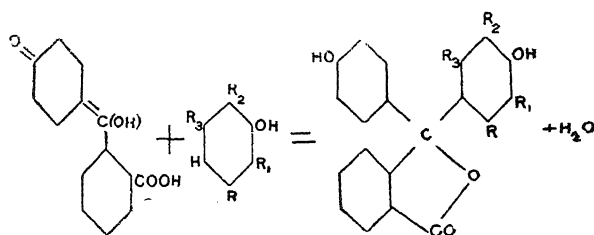


where R, $R_1$, $R_2$, $R_3$ may be H, OH, $NH_2$, $N(CH_3)_2$, $N(C_2H_5)_2$, etc. In constitution these substances are closely allied to phenol-phthalein and have chemical and physical properties similar to that substance. All of them dissolve in alkalies with a bright crimson colour with the exception of α-naphthol derivative which develops a blue colour with these reagents. None of them have got any fluorescence in solution with the exception of the resorcinol derivative, which shows

the phenomenon in a very weak manner. From the point of view of absorption spectra it is found that the amount of colour development is practically dependent only on the load factor in the vicinity of the quinonoid linkage. *Para*-quinonoid compounds of the type derived from catechol, *ortho*-cresol or a-naphthol are undoubtedly more coloured than the *ortho*-quinonoid compounds of the type derived from *p*-cresol, quinol, ß-naphthol or 2:7-dihydroxy-naphthalene. The nomenclature of these substances can be arrived at by considering them as derivatives of phthalophenone,
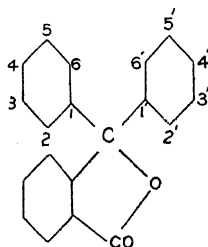


PHTHALOPHENONE

just as phenol-phthalein itself can be regarded as 4:4'-dihydroxy-phthalophenone. In presence of alkali these substances, which are nearly always colourless in the solid state or in neutral solvents, develop intense colour due to the formation of a *para*-quinonoid structure as is well known in the classical example of phenol-phthalein, thus :—



COLOURLESS                    RED PHENOL-PHTHALEIN
PHENOL-PHTHALEIN.             (QUINONOID DISODIUM SALT).
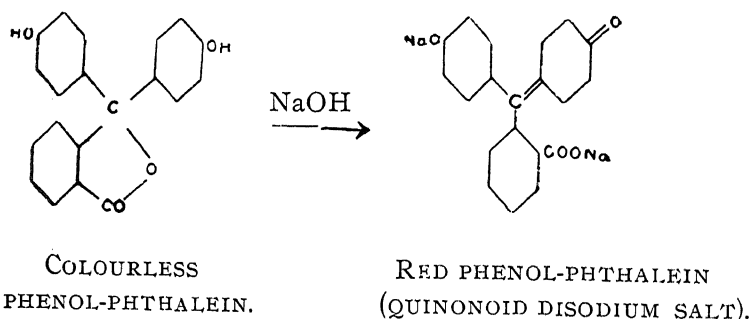
An *ortho*-quinonoid structure is also possible in cases of *p*-cresol, quinol, etc., thus:—
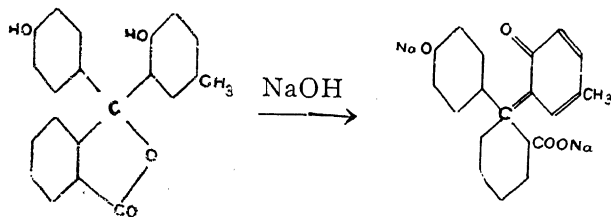


The following aromatic hydroxy and amino-hydroxy compounds have been condensed with *p*-hydroxy-benzoyl-benzoic acid and the corresponding phthalophenone derivatives obtained: phenol, catechol, resorcinol, quinol, pyrogallol,

phloroglucinol, o-cresol, m-cresol, p-cresol, thymol, carvacrol, α-naphthol, β-naphthol, 2 : 7-dihydroxy-naphthalene, m-dimethyl-amido-phenol and m-diethyl-amido-phenol. The absorption spectra and other properties of these compounds have been given in the form of a table at the end of the paper.

## EXPERIMENTAL.

**p-hydroxy-benzoyl-benzoic acid.** – It was prepared according to the method of Friedlander[2] from phenol-phthalein, viâ the oxime. 50 g. of phenol-phthalein was dissolved in 500 c.c. of 10 per cent caustic potash solution and to it was added 18 g. hydroxylamine hydrochloride. The mixture was gently heated over a small flame. The deep red colour gradually decreased and finally became yellow. On addition of some alcohol and acetic acid the oxime separated as an yellow compound. It was washed and dried. On crystallization from dilute alcohol it melted at 212° with decomposition.

The oxime was next digested with dilute sulphuric acid. On boiling the yellow colour vanished and whitish yellow crystals began to separate. It was allowed to cool. The crude p-hydroxy-benzoyl-benzoic acid thus obtained was crystallised from dilute alcohol and animal charcoal. It was obtained as white crystalline plates, m.p. 210° (yield 26 g.)

**4 : 4'-dihydroxy-phthalophenone.** —p-hydroxy-benzoyl-benzoic acid (15 g.) was heated with pure phenol (7·5 g.) and concentrated sulphuric acid (4 c.c.) in an oil bath maintained at 125° for two hours. The temperature was slowly raised to 140°. The condensed product was steam distilled to remove unacted phenol. The product was dissolved in dilute sodium hydroxide, filtered and precipitated by dilute hydrochloric acid when a white flocculent precipitate was obtained. On crystallization from alcohol it was obtained as colourless crusts (yield 11 g.)

**4 : 4′: 5′-trihydroxy-phthalophenone.** – It was obtained in a similar manner to the above by condensing p-hydroxy-benzoyl-benzoic acid and catechol in presence of sulphuric acid for 3 hours The temperature was maintained as above (yield 41 %).

**4 : 4′:6′-trihydroxy-phthalophenone.** - This substance was obtained from p hydroxy-benzoyl-benzoic acid and resorcinol in presence of concentrated sulphuric acid. The condenced product exhibited a green fluorescence in alkali solution. The fluorescence was considerably decreased in the purified product obtained on crystallization from alcohol (yield 58%).

**4 : 3′: 6′-trihydroxy-phthalophenone.** —It was obtained in a similar manner to the catechol compound by condensing p-hydroxy-benzoyl-benzoic acid with quinol. It was crystallized from dilute acetic acid (yield 49 %).

**4 : 3′: 4′: 5′-tetrahydroxy-phthalophenone.** —p-hydroxy-benzoyl-benzoic acid (9 g.), pyrogallol (6 g.) and concentrated sulphuric acid (2 c. c) was heated at 120°—130° for 6 hours. The condensation product was dissolved in absolute alcohol and

precipitated with petroleum ether. It was crystallised from glacial acetic acid (yield 46 %).

**4 : 2′: 4′: 6′-tetrahydroxy-phthalophenone.**—It was prepared by heating phloroglucinol and *p*-hydroxy-benzoyl-benzoic acid in presence of sulphuric acid for two hours at 150° and finally raising the temperature to 190°. It was crystallised from glacial acetic acid (yield 54 %)

**4 : 4′-dihydroxy-5′-methyl-phthalophenone.**—A mixture of 3 g. of the acid with 1·6 g. of *ortho*-cresol was heated for four hours at 130° with concentrated sulphuric acid as condensing agent. The melt was extracted with dilute caustic soda solution and precipitated with acetic acid. The phthalophenone was crystallised from dilute alcohol (yield 63 %)

**4 : 4′-dihydroxy-6′-methyl-phthalophenone.**—It was prepared from *meta*-cresol in a similar manner to the above with the only difference that it was heated for 8 hours (yield 52 %)

**4 : 6′-dihydroxy-3′-methyl-phthalophenone.**—This substance was obtained by heating *p*-hydroxy-benzoyl-benzoic acid and *para*-cresol for 9 hours at 125° in presence of strong sulphuric acid (yield 54 %)

**4 : 4′-dihydroxy-6′-methyl-3′-isopropyl-phthalophenone.**—A mixture of 2 5 g. of the acid, 1·8 g. of thymol and 3 g. of tin-tetrachloride was heated at 130°-35° for seven hours. The melt was extracted with dilute ammonia, filtered and the phthalophenone precipitated by acetic acid. It was crystallised from dilute alcohol (yield 49 %)

**4 : 4′-dihydroxy-3′-methyl-6′-isopropyl-phthalophenone.**—It was prepared from the acid and carvacrol in a similar manner to the above with the difference that it was heated for 8 hours at 130°. (yield 39 %)

**4 : 4′-dihydroxy-2′: 3′-phenylene-phthalophenone.**—A mixture of 2·5 g. of *p*-hydroxy-benzoyl-benzoic acid, 1·9 g. of α-naphthol and 8 drops of concentrated sulphuric acid was heated for 8 hours at 140° The melt was dissolved in dilute caustic soda solution and precipitated with acetic acid. The precipitate was crystallised from dilute alcohol. (yield 42%)

**4 : 6′-dihydroxy-3′: 4′-phenylene-phthalophenone.**—It was prepared from β-naphthol and the acid in a similar manner to the above (yield 39 %)

**4 : 6′-dihydroxy-3′: 4 ′(4″-hydroxy) phenylene-phthalophenone.**—This substance was prepared from 2 : 7-dihydroxy-naphthalene and *p*-hydroxy-benzoyl-benzoic acid in a manner similar to the above (yield 38 %)

**4 : 6′-dihydroxy-4′-dimethylamino-phthalophenone.**—A mixture of the acid (5 g.), *meta*-dimethylamido-phenol (3·6 g.) and concentrated sulphuric acid (1·5 g.) was heated at 135° for 4 hours. The melt was extracted with dilute sodium hydroxide solution and precipitated with dilute hydrochloric acid. The precipitate was crystallised from dilute alcohol (yield 57 %)

**4 : 6′-dihydroxy-4′-diethylamino-phthalophenone.**—This substance was prepared from *meta*-diethylamido-phenol and *p*-hydroxy-benzoyl-benzoic acid in a manner similar to the above (yield 55 %)

*Properties of Phthalophenones.*

| Name (P=phthalophenone) | Appearance | M. P. | Colour in Caustic Soda solution. | Absorption maxima (λ) | Analyses (Theoretical values in brackets). |
|---|---|---|---|---|---|
| 1. 4:4'—dihydroxy—P ... | white | 252° | crimson red | 5560 | {C=75·43 (75·49); H=4·36 (4·40)%. |
| 2. 4:4':5'—trihydroxy—P ... | grey | 148—49° | pink red | 5605 | ... |
| 3. 4:4':6'—trihydroxy—P ... | yellow | 164° | {red with green fluorescence | 5590 | {C=71·46 (71·85); H=4·02 (4·19)%. |
| 4. 4:3':6—trihydroxy—P ... | white | 153—55° | red | 5595 | ... |
| 5. 4:3':4':5'—tetrahydroxy—P ... | dirty white | 247—48° | Violet pink | 5575 | ... |
| 6. 4:2':4':6'—tetrahydroxy—P ... | white | 256° | red | 5660 | {C=68·04 (68·57); H=4·14 (4·00)%. |
| 7. 4:4'—dihydroxy—5'—methyl—P ... | " | 117° | " | 5730 | {C=75·68 (75·90); H=5·02 (4·82)%. |
| 8. 4:4'—dihydroxy—6'—methyl—P ... | " | 131° | pink | 5620 | ... |
| 9. 4:6'—dihydroxy—3'—methyl—P ... | " | 135° | " | 5615 | ... |
| 10. 4:4'—dihydroxy—6'—methyl—3'—iso-propyl—P ... | dirty white | 231—32° | Violet-pink. | 5825 | {C=76·54 (77·00); H=5·86 (5·88)%. |
| 11. 4:4'—dihydroxy—3'—methyl—6'—iso-propyl—P ... | " | 178—79° | " | 5790 | ... |
| 12. 4:4'—dihydroxy—2':3'—phenylene—P | buff | 171° | blue | 6125 | {C=77·86 (78·26); H=4·36 (4·34)%. |
| 13. 4:6'—dihydroxy—3':4'—phenylene—P | pink | 153° | pink | 5605 | ... |
| 14. 4:6'—dihydroxy—3':4'(4''—hydroxy)phenylene—P ... | violet | 261° | Violet | 5635 | {C=74·82 (75·00); H=4·08 (4·16)%. |
| 15. 4:6'—dihydroxy—4'—dimethylamino—P | pink-violet | 142° | Violet-pink | 6030 | ... |
| 16. 4:6'—dihydroxy—4'—dimethylamino—P | " | 93° | " | 6060 | {C=73·67 (74·03); H=5·79 (5·91).% |

The author expresses his best thanks to Dr. S. Dutt for his kind help and encouragement during the progress of the work.

### References:

1. Ghatak and Dutt. *J. Indian Chem. Soc.*, *6*, 465, 1929.
2  Friedlander, *Abs.*, *J. Chem, Soc.*, I, 273, 1893.

# CHEMICAL EXAMINATION OF THE ROOTS OF *THEVETIA NERIIFOLIA* (JUSS)

By N. Ghatak and G. P. Pendse,

Chemistry Department, University of Allahabad.

Every part of the plant of *Thevetia neriifolia* of the natural order *Apocynaceœ* or yellow oleander as it is known in English and *pila-kaner* in Hindustani, is considered to have poisonous properties. The bark, leaves and roots of the plant have, therefore, been used in regulated doses as remedies for various ailments. In a previous paper[1] the results of examination of the seeds of the plant have been recorded. As no work has yet been done on the root of *Thevetia neriifolia*, its examination was undertaken with a view to study the nature of the chemical compounds contained in it. The analyses have proved the presence of a new hydrocarbon, some quantity of a wax, little volatile oil, some quantity of thevetin — a glucoside which has been recorded in the examination of the seeds and a considerable amount of the substance which yields Warden's[2] *thevetin-blue*. The results of examination have been recorded in the experimental part of the paper.

## Experimental

Fresh roots of *Thevetia neriifolia* was washed well of mud and other impurities and cut to small pieces by means of a chopper. The pieces were spread on paper and allowed to dry in air for three days. It was then found to contain 7·5 per cent of moisture and on incineration left 3·7 per cent of ash.

A preliminary examination of the roots showed the absence of alkaloids.

F, 8

For complete analysis 2 kilos of the chopped and air dried roots were extracted with boiling rectified spirit in a round bottom extraction flask (capacity 5 litres). The filtrate on cooling deposited small quantity of a white flocculent precipitate. The precipitate was filtered and similar precipitates of subsequent extractions were collected together. On drying it weighed 14 g. The extraction of the roots was continued till the extract left only traces of residue on complete evaporation of the solvent. The combined extract was next concentrated under reduced pressure to one-third of its volume and on leaving overnight deposited a brown deposit. The precipitate on filtration and drying in a desiccator weighed 21 g. The filtrate was again concentrated under reduced pressure to a volume of about 500 c. c. and was obtained as a brown syrupy liquid having a disagreeable odour. The first precipitate, second precipitate and the thick mother liquor were then separately analysed.

*First precipitate.*—The substance which was of a dirty white colour was extracted with boiling petroleum ether (b. p. 35°—60°) and filtered. The filtrate on concentration deposited white needle-shaped soft crystals. The product on recrystallization from the same solvent and remaining in the vacuum desiccator for two days melted at 79-80°. This substance burns with a non-luminous flame, which soon becomes luminous and on extinction of the flame gives out fumes having the characteristic smell of burnt paraffin. The molecular formula of this compound has been determined to be $C_{43} H_{86}$. No compound of this formula and possessing properties identical with it has hitherto been recorded in chemical literature. It is, therefore, proposed to designate the new compound *thevetene*, with reference to its properties of a hydrocarbon and the generic name of the plant from which it has been isolated.

*Thevetene.*—In ether, benzene, petroleum ether, carbon tetrachloride, chloroform and ethyl alcohol it is sparingly soluble in the cold but dissolves in them to a small extent on heating. Thevetene is insoluble in pyridine, ethyl acetate and acetone. In concentrated sulphuric acid it turns slightly brown and on heating decomposes with charring. Concentrated and fuming nitric acids have no effect on the substance.

[Found : C, 85·28, 84·98, 85·39, 85·34; H, 14·32, 14·28, 14·37, 14·31 ; M. W. (ebullioscopic in benzene) 603, 599, 594, 610. $C_{43} H_{86}$, requires, C, 85·71, H, 14·28. M. W., 602.]

*Dibromo-thevetene.*— 0·5 g. of the substance was dissolved in 50 c.c. pure carbon tetrachloride on boiling. To this was added 5 c.c. of carbon tetrachloride containing few drops of liquid bromine. The flask containing these substances was heated over water bath for five minutes and was then allowed to stand for spontaneous evaporation of the solvent. On complete evaporation of carbon tetrachloride a light brownish-yellow crust was left at the bottom. It was powdered and dried in a vacuum desiccator for three days when it melted at 87°-88°.

[Found: Br, 21·68 % ; $C_{43} H_{86} Br_2$, requires, Br, 20·97%.]

*Second precipitate.* – The soft brown mass was extracted with cold ether (10°) several times till the extract was colourless. The residue on crystallization from benzene was obtained as white soft mass and was identified to be thevetene. The combined ethereal extract on distillation of the solvent left a brown waxy product possessing a disagreeable odour. This was steam distilled. When the distillate amounted to about 300 c. c., it was extracted with ether. The extract on complete removal of ether left about a c.c. of an oily substance having the characteristic odour of the original substance. The quantity of the oil being too small, it could not be further analysed. The product left in the flask after steam distillation was identified to be a wax.

*The thick brown mother liquor.* –It was distilled under reduced pressure (10 mm.) till it was obtained as a soft solid mass. It was then extracted several times with ether to remove the oily and waxy contaminations. The product was then extracted with boiling chloroform. The chloroform extract on complete removal of the solvent left small quantity of a brown pasty solid (about 2 g.). It was soluble in ethyl acetate. The substance was twice crystallized from dilute alcohol and animal charcoal, when it was obtained as white slender needles melting at 192°. It was identified to be thevetin, a glucoside which was isolated and described in the paper[1] on the examination of the seeds of *Thevetia neriifolia*.

The residue left after chloroform extraction readily reduced Fehling's solution, Tollens reagent and ammoniacal silver nitrate. The whole mass was dissolved in 400 c.c. of water and to it was added lead acetate solution. The precipitate, which was of a yellowish-white colour, was filtered off and the filtrate was reprecipitated with saturated solution of tannic acid. The filtrate was freed from tannic acid by barium hydroxide solution and filtered. Excess of barium in the solution was removed by passing a current of carbon dioxide in it. The filtrate now became very light brown in colour. A little of this solution on treatment with concentrated hydrochloric acid developed greenish-blue colour and on warming deposited a flocculent precipitate of brown colour. This compound corresponded to Warden's[2] *thevetin-blue*, a reference of which has already been made in a previous communication. Every attempt to separate the compound, which developed greenish-blue colour, in a pure form was unsuccessful. The whole of the mother liquor was, therefore, warmed with a few c. c. of concentrated hydrochloric acid and the brown precipitate was filtered and washed free from soluble impurities. On drying it became brown black in colour and weighed 6·4 g. It does not melt even on heating to 300°. This substance is insoluble in all organic solvents excepting pyridine, in which it dissolves with a brown colour. From the pyridine solution it was precipitated by addition of water and was obtained as a brown-black amorphous powder. It does not contain nitrogen. This substance has been named *neriifolin*, with reference to the specific name of the plant from which it has been isolated. On combustion the substance was found to contain C=60·87% and H=4·64%. The only

derivative of this substance that could be prepared was the reduced and simultaneously acetylated one.

*Reduced and acetylated neriifolin.*—3 g. of neriifolin, 8 g. of finely powdered zinc dust and 50 c.c. acetic anhydride were put in a flask and put under reflux. Few drops of water were added when the evolution of hydrogen started. It was then gently heated. When the reaction slowed down few drops of water were again added. The operation was repeated several times till the zinc dust was completely used up. It was then filtered hot. The filtrate on dilution and neutralization with ammonia gave a brown pasty deposit at the bottom which slowly solidified. It was crystallized from alcohol and animal charcoal. A micro-crystalline white powder was obtained which melted at 93°. This substance gave pink and yellow colour reactions with concentrated sulphuric and nitric acids respectively.

On combusting the substance the following results were obtained: C=63·52% and H=7·04%.

Our best thanks are due to Dr. S. Dutt, for his kind interest in the work.

*References.*

[1] Ghatak, *Bull. Acad. Sci., U. P.*, 79, 2, 1932.
[2] Warden, *Brit. Chem. Abs.*, II, 1126, 1882

# ON THE MAXIMUM MODULUS PRINCIPLE

By P. L. Srivastava and S. P. Jain,

Mathematics Department, Allahabad University.

1. In a recent joint paper[1] of ours we have studied the singularities of the function $f(s)$ defined by the Laplace-Abel integral

$$\int_0^\infty \phi(z)\, e^{-sz} dz,$$

where $\phi(z)$ is an analytic function of $z$ $(= \rho e^{i\psi})$ of exponential type in the angular region $|\psi| \leq a$, $a > 0$. The results obtained in this paper have now enabled us to establish the following theorem which is the main purpose of this note.

*Theorem I—*

*If*

(1·1)     $\phi(z)$ *be an analytic function of* $z$ *in the angle* $|\psi| \leq a < \dfrac{\pi}{2}$, *and satisfy the relation* $\phi(z) = O(e^{M\rho})$, $(M > 0)$, *throughout this angle* ;

(1·2)     *the integral* $\int_0^\infty \left| \phi\left( \rho e^{\pm ia} \right) \right| d\rho$ *be convergent* ;

*then* $\phi(z) = O(e^{\epsilon\rho})$ *throughout the region* $|\psi| \leq a$, $\epsilon$ *being any positive number howsoever small.*

This result is analogous to a well-known theorem of Phragmén-Lindelöf,[2] which differs from it only in having in place of (1·2)

(1·3)     $\phi'(z) = O(1)$ on the boundary lines $\psi = \pm a$, and in proving that $\phi(z)$ is bounded throughout the angular region

It is obvious that (1·3) does not imply (1·2). To see that the convergence of $\int^\infty |F(x)|\, dx$ does not imply that $F(x) = O(1)$, take $F(x) = \dfrac{x^2}{1 + x^7 \sin^2 x}$. Here $\int^\infty |F(x)|\, dx$ is convergent[3], but $F(x)$ is not bounded as $x \longrightarrow \infty$. In fact, at points on the $x$-axis $F(x)$ is as large as $x^2$. It follows, therefore, that neither of (1·2)

and (1·3) implies by itself the other, and so none of the above two theorems seems included in the other.

2. *Proof of Theorem I.*

Let $\phi(0) = c$, and let
$$\phi_1(z) \equiv \phi(z) - c.$$

Consider the function defined by
$$f(s) = \int_0^\infty \phi_1(z) e^{-sz} dz.$$

Proceeding as in theorem I of our paper[1], $f(s)$ can be proved to be an analytic function of $s$ $(=re^{i\theta})$ in the interior of the angular region bounded by the radii vectors $\theta = \pm \left(\dfrac{\pi}{2} + a\right)$, and of order $\left(\dfrac{1}{|s|^2}\right)$ throughout the same region.

Conversely, applying theorems II and III of our paper[1], we can show that $\phi_1(z)$ is an analytic function of $z$ in the angular region $|\psi| \leqq a$, and satisfies throughout that region the relation $\phi(z) = O(e^{\epsilon\rho})$, $\epsilon$ being any positive number howsoever small.

Now
$$|\phi(z)| = |\phi_1(z) + c|$$
$$\leqq |\phi_1(z)| + |c|$$
$$= O(e^{\epsilon\rho}) + |c|$$
$$= O(e^{\epsilon'\rho})$$

where $\epsilon'$ is another arbitrarily small positive number.

*Corollary. If $\phi(z)$ be an analytic function of exponential type in an angular region including the ray $\psi = a$,*

*and* $\displaystyle\int_0^\infty \left|\phi(\rho e^{ia})\right| d\rho$ *be convergent, then,* $\phi(\rho e^{ia}) = O(e^{\epsilon\rho})$.

This can be proved in the same manner as theorem I.

3. An immediate consequence of theorem I is the following theorem.

*Theorem II—*

*If $\phi(z)$ satisfies (1·1), and*

3·1    $$\int_0^\infty \left|\phi(\rho e^{\pm ia})\right| e^{-k\rho} d\rho \text{ is convergent, } (k>0);$$

*then* $\quad \overline{\lim_{\rho \to \infty}} \dfrac{\log|\phi(\rho e^{i\psi})|}{\rho} \leqq k \sec a \cos \psi \text{ for } |\psi| \leqq a.$

Let $\phi(z) \equiv \phi_1(z) e^{zk \sec a}$.    Then $\phi_1(z)$ satisfies the conditions of Theorem I, and consequently

$$\phi_1(z) = O(e^{\epsilon \rho}) \text{ throughout } |\psi| \leqq \alpha.$$

Hence $\varlimsup\limits_{\rho \longrightarrow \infty} \dfrac{\log|\phi(\rho e^{i\psi})|}{\rho} \leq k \sec \alpha \cos \psi.$

4.  Similar analysis enables us to suggest new proofs of the well-known theorems of Riesz and Carlson[4]. Take, for instance, Riesz's theorem which is as follows :—

*If*

(4.1)      $\phi(z)$ *is analytic in the half-plane* $R(z) \geqq 0$, *and is of exponential type* ;

(4.2)      $\phi(z) = O(e^{-\delta \rho})$, $\delta > 0$, *on the imaginary axis* ;

*then* $\phi(z) \equiv 0.$

Consider $f(s) = \displaystyle\int_0^\infty \phi(z) \, e^{-sz} \, dz.$

Then proceeding as in theorem I of our paper[1], $f(s)$ can be proved to be an integral function of $s$ and of order $\left(\dfrac{1}{|s|}\right)$ as $|s| \longrightarrow \infty$ and so $f(s) \equiv 0.$

Hence $\phi(z) \equiv 0.$

To prove Carlson's theorem, consider the function $g(z) \equiv \dfrac{\phi(z)}{\sin \pi z}$, and apply Riesz's theorem to $g(z)$.

5.  Mittag-Leffler[5] has given some examples of integral functions defined by means of Taylor's series which tend to zero uniformly in the whole plane except in an arbitrarily small angular region. We take this opportunity of pointing out that such functions can also be defined by means of the Laplace-Abel integral.

Suppose $\phi(z)$ is an analytic function of $z$ in the half-plane $R(z) \geqq 0$, and $\phi(z) = O(e^{\epsilon \rho})$ for every positive $\epsilon$ throughout the half-plane. Suppose further that for some values of $\psi$, say, $\psi = 0$, $\phi(\rho e^{i\psi}) = O(e^{-\Delta \rho})$, where $\Delta$ is any arbitrarily positive number howsoever large. An example of such a function $\phi(z)$ is $\dfrac{1}{[\log(z+\beta)]^z}$, where $\beta > 1$, and $[\log(z+\beta)]^z$ has its principal value. Then $f(s)$ defined by $\displaystyle\int_0^\infty \phi(z) \, e^{-sz} \, dz$ will be an integral function of $s$, and outside the strip $|t| \leqq \delta, \sigma \leqq \delta'$, where $\delta$ and $\delta'$ are any positive numbers howsoever small, it will be of order $\dfrac{1}{|s|}$ so that it will tend to zero as $|s| \longrightarrow \infty$ uniformly in the whole region except the above-mentioned strip.

Further, we may observe that the order of $f(s)$ in the strip must be greater than that of $e^{k\rho}$, unless $\phi(z) \equiv 0$. For if $f(s) = O(e^{k\rho})$ in this strip, and is bounded throughout the rest of the plane, then $f(s)$ must reduce to a constant, which must be zero here. That is, $f(s) \equiv 0$, and so $\phi(z) \equiv 0$. This is a contradiction.

*References.*

[1] Srivastava and Jain : *Bul. Acad. Sci., U. P.*, **2**, 53, 1932.

[2] Phragmén and Lindelöf : *Acta Mathematica*, **31**, 381, 1908.

[3] Bromwich : *Infinite Series.* pp. 469-470 (2nd Ed.).

[4] M. Riesz : *Proc. Camb. Phil. Soc.*, **20**, 205, 1920.

[5] Lindelöf : *Calcul des Residues*, pp. 119—121.

# BUSINESS MATTERS

# Business Supplement

## ANNUAL MEETING

The Annual Meeting of the Academy of Sciences was held in the Vizianagram Hall, Muir College Buildings, Allahabad, at 3 p.m. on Friday, January 13, 1933. The Hon'ble Mr. J. P. Srivastava, M.Sc. (Tech.), Education Minister, presided over the function. On account of unavoidable absence of Professors P. S. MacMahon and A. C. Banerji, the General Secretaries, Dr. P. L. Srivastava read the Annual Report of the Academy of Sciences.

Prof M. N. Saha, the President of the Academy, read his address. The Hon'ble Mr. J. P. Srivastava then delivered his speech.

Prof. K. N. Bahl, proposed a vote of thanks to the Hon'ble Minister and Prof. N. R. Dhar seconded the vote of thanks.

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# SECRETARIES' REPORT

WE HAVE the honour to submit the following report on the working of the Academy during the period beginning from the 1st of January, 1932, and ending on the 31st of March, 1933 :—

The most notable event of the year under review was the inaugural meeting of the Academy, which was held in the Vizianagram Hall, Muir Central College Buildings, Allahabad, on Tuesday, March 1, 1932. The success of the function was mainly due to the inspiring presence of His Excellency Sir Malcolm Hailey, G.C.I.E., K.C.S.I., I.C.S., the Patron of the Academy, who presided over the meeting. His Excellency takes a keen personal interest in the affairs of the Academy, and has been pleased to sanction a non-recurring grant of Rs. 2,000 to the Academy for the current financial year.

The Academy has now on its roll 102 members, of whom nineteen are non-resident members. Pandit Madan Mohan Malaviya, Vice-Chancellor of the Benares Hindu University, has been elected an Honorary Fellow of the Academy in recognition of his eminent services in the cause of science and education in these Provinces. Three new Fellows, viz., Dr. Rudolf Samuel, Dr. Robert F. Hunter, and Dr. P. L. Srivastava, have also been elected. We have to report, with great regret, that the Academy had to mourn the loss, by death, of two members of the Academy, viz., Mr. Nabendu Bhusan Banerji, a promising young member of the Academy, and Dr. W. Dudgeon, a botanist of repute.

The Academy has decided that some of its ordinary meetings may also be held at other University and educational centres where there is a sufficient number of members to form a quorum and where the members are prepared to make necessary arrangements for the meeting. For the convenience of the Christian members of the Academy the meetings are generally held on week days. During the period under review 43 papers were read.

The Academy is indebted to Mr. W. G. P. Wall, M.Sc., I.E.S., Assistant Director of Public Instruction, U.P., for his generous gift of a large number of volumes of different scientific journals to the Academy. The Academy has already published the first volume as well as first and second parts of the second volume of its Bulletin. It has received good recognition in India as well as outside India, and we are already receiving 53 foreign and Indian scientific journals in exchange. The work done by the Academy has attracted the attention of the scientific world. NATURE, the premier scientific journal of Great Britain, welcomes, in its issue of October 8, 1932, the successful inauguration of the Academy, and feels little doubt that the future success of the Academy is assured, and that it will do much to stimulate the research spirit in the Universities of the United Provinces of Agra and Oudh. The need for a building of the Academy is urgently felt. With the help of the Government, the Universities of these Provinces, and generous public we hope that it will be possible for us to construct a building for the Academy before long.

The secretaries wish to express their thanks to Dr. D. R. Bhattacharya, Hony. Treasurer, for his ungrudging help and active co-operation.

## ABSTRACTS OF THE PROCEEDINGS

The list of the Office-Bearers and Members of the Council to which the management of the affairs of the Academy was entrusted for the year 1932-33 is given in appendix A.

Appendix B contains the list of names of 102 members who were on the roll of the Academy on March 31, 1933.

The Council expressed its deep gratitude to the Government for the Non-recurring grant of Rs. 2,000 awarded to the Academy for the year 1932-33.

The Council gratefully accepted the generous offer of the Hon'ble Mr. J. P. Srivastava, M. Sc. (Tech.), Education Minister, to found a Gold Medal to be awarded to the author of the best paper read before the Academy in any year.

The Council accepted with thanks the generous gift of 59 volumes of different scientific journals to the Academy from Mr. W. G. P. Wall, M. Sc, I. E. S., Assistant Director of Public Instruction of the United Provinces.

Pandit Madan Mohan Malaviya, B. A., LL. D., Vice-Chancellor, Benares Hindu University was elected an Honorary Fellow of the Academy of Science, U. P. on account of his eminent services for the cause of education and science, on the 6th of August, 1932.

The following three members were elected Fellows of the Academy in the Fellow's meeting held on November 30, 1932.

1. Prof. Dr. Rudolf Samuel, Ph. D., Muslim University, Aligarh. U. P.
2. Prof. Dr. Robert F. Hunter, D. Sc., Ph. D., Muslim University, Aligarh, U P.
3. Dr. P. L. Srivastava, M A., D. Phil., Allahabad University, Allahabad.

The following members were elected Office-Bearers and the Members of the Council for the year 1933 in the Annual meeting held on January 13, 1933.

### President:

1. Prof. K. N. Bahl., D.Phil, D.Sc.

### Vice-Presidents :

2. Prof. M. N. Saha, D.Sc., F.R.S., F.A.S.B., F.Inst.P., P R.S.
3. Prof. B. Sahni, D.Sc., Sc. D., F.L.S., F.A.S.B.

### Hony. Treasurer:

4. Prof. D. R. Bhattacharya, M.Sc., Ph.D., D.Sc, F.Z. S.

### General Secretaries :

5. Prof. P. S. MacMahon, B.Sc., M.Sc., F.I.C.
6. Prof. A. C. Banerji, M.A., M Sc., F.R A.S., I.E.S.

### Foreign Secretary:

7. Prof. N. R. Dhar, D.Sc , F I.C., I.E.S.

### Other Members of the Council:

8. Prof. K. C. Mehta, Ph. D , M.Sc.
9. Dr. S. S. Nehru, M.A , Ph.D., I.C.S., M.L.C.
10. Prof. Ch. Wali Mohammad, M.A , Ph.D., I.E.S.
11. Prof. K. K. Mathur, B.Sc., A R.S.M.
12. Dr. P. L. Srivastava, M.A., D.Phil.
13. Prof. Robert F. Hunter, D.Sc , Ph.D.
14. Dr. S. M. Sane, B.Sc., Ph.D.
15. Prof. C. Maya Das, B.Sc., M A., I.A.S
16. Prof. K. C. Pandya, D.Sc.

# APPENDIX A

## LIST OF OFFICE-BEARERS AND MEMBERS OF THE COUNCIL.

### 1932

#### President:

1. Prof. M. N. Saha, D.Sc. (Cal.), F.R.S., F.A.S.B., F. Inst. P, P. R. Scholar, Professor of Physics, Allahabad University, Allahabad.

#### Vice-Presidents:

2. Prof. N. R. Dhar, D.Sc. (Lond.), Docteur ès Sciences (Paris), F.I.C., I.E.S., Professor of Chemistry, Allahabad University, Allahabad.
3. Prof. K. N. Bahl, D. Phil. (Oxon.), D. Sc. (Punjab), Professor of Zoology Lucknow University, Lucknow.

#### Hony. Treasurer:

4. Prof. D. R. Bhattacharya, M.Sc. (All.), Ph. D. (Dublin), Docteur ès Sciences (Paris), Professor of Zoology, Allahabad University, Allahabad.

#### General Secretaries:

5. Prof. P. S. MacMahon, B.Sc., (Oxon), M.Sc. (Manchester), F.I.C, Professor of Chemistry, Lucknow University, Lucknow.
6. Prof. A. C. Banerji, M.Sc. (Cal.), M.A. (Cantab), F.R.A S. (Eng.), I. E. S., Professor of Mathematics, Allahabad University, Allahabad.

#### Foreign Secretary:

7. Prof. Ch. Wali Mohammad, B.A. (Cantab), Ph. D. (Göttingen), I. E. S. Professor of Physics, Lucknow University, Lucknow.

#### Other Members of the Council:

8. Prof. K. C. Mehta, Ph.D. (Cantab), M. Sc. (Punjab), Professor of Botany, Agra College, Agra.
9. Dr. S. S. Nehru, M.A., Ph.D., I.C.S., M.L.C., Deputy Secretary to Government, U.P., Publicity Department, Lucknow.
10. Prof. H. D. H. Drane, M.Sc., Ph.D., A.M.I.E.E., A.M.I. Chem. E., Principal, Harcourt Butler Technological Institute, Cawnpore

11. Prof. K. K. Mathur, B.Sc. (Hons., Lond.), A.R.S.M., Professor of Geology, Benares Hindu University, Benares.

12. Dr. Luxmi Narayan, D.Sc., (All.), Reader in Mathematics, Lucknow University, Lucknow.

13. Dr. D. N. Forman, M.D., Jumna Mission Dispensary, Allahabad City.

14. Prof. B. Sahni, D.Sc (Lond.), Sc.D. (Cantab), F.L.S., F.A.S.B., Professor of Botany, Lucknow University, Lucknow.

15. Dr. P. L. Srivastava, M.A., D.Phil. (Oxon), Reader in Mathematics, Allahabad University, Allahabad.

16. Prof. André Weil, Docteur ès Sciences (Paris), 3. Rue Auguste—Comte, Paris '6c', France.

# APPENDIX B

## ORDINARY MEMBERS

R—Resident.  N—Non-Resident.

*—Denotes a Fellow.

| Date of Election. | | |
|---|---|---|
| 17-4-1931 | R | Asundi, (R.K.), Ph.D., Reader, Physics Department, Muslim University, Aligarh. |
| 21-12-1931 | N | Bagchi, (S.C.), B.A., LL.D., Principal, Law College, Calcutta. |
| 1-1-1930 | R* | Bahl, (K.N.), D. Phil., D.Sc., Professor of Zoology, Lucknow University, Lucknow. |
| 1-1-1930 | R* | Banerji, (A C.), M.A, M.Sc., F.R.A.S., I.E.S , Professor of Mathematics, Allahabad University, Allahabad. |
| 29-2-1932 | R | Banerji, (G.N.), The Scientific Instrument Company Ltd., Albert Road, Allahabad. |
| 22-12-1932 | N | Banerji, (S.K.), D.Sc., Meteorological Office, Ganeshkhind Road, Poona 5. |
| 17-4-1931 | N | Basu, Saradindu, M Sc., Meteorologist, Ganeshkhind Road, Poona 5. |
| 19-3-1931 | R | Bhargava, Saligram., M.Sc., Reader, Physics Department, Allahabad University, Allahabad. |
| 17-4-1931 | R | Bhargava, Vashishta , M Sc., I.C.S., Assistant Magistrate and Collector, Budaun. |
| 17-4-1931 | R | Bhatia, (K.B.), I.C.S., Joint Magistrate, Shahjahanpur. |
| 1-1-1931 | R* | Bhattacharya, (D.R.,) M.Sc., Ph.D. Docteur ès Sciences, Professor of Zoology, Allahabad University, Allahabad. |
| 17-4-1931 | R | Bhattacharya, (D.P.), M.Sc., Bareilly College, Bareilly. |
| 3-4-1933 | R | Chand, Tara, M. A., D.Phil., Principal, K. P. University College, Allahabad. |
| 29-2-1932 | R | Charan, Shyama., M.A, M.Sc., (Lond), Agra College, Agra. |
| 1-1-1930 | R* | Chatterji, (G.), M.Sc., Meteorologist, Upper Air Observatory, Agra. |
| 17-4-1931 | R | Chatterji, (K.P.), M.Sc., A.I.C., F.C.S , Reader, Chemistry Department, Allahabad University, Allahabad. |
| 17-4-1931 | R | Chatterji, (A.C.), D.Sc., Chemistry Department, Lucknow University, Lucknow. |
| 19-3-1931 | R | Chaudhury, Rabindra Nath, M.Sc., M.A., Mathematics Department, Allahabad University, Allahabad. |

8

| Date of Election. | | Alphabetical List of Ordinary Members |
|---|---|---|
| 17-4-1931 | R | Chaudhury, (H.P.), M.Sc., Lucknow University, Lucknow. |
| 19-3-1931 | R | Das, Ramsaran, D.Sc., Zoology Department, Allahabad University, Allahabad. |
| 17-4-1931 | R | Das, C. Maya, M.A., B.Sc, I.A.S., Principal, Agricultural College, Cawnpore. |
| 28-10-1932 | N | Das, (A.K), D.Sc., Alipore Observatory, Alipore, Calcutta. |
| 22-12-1932 | N | Das, (B.K), D.Sc., Professor of Zoology, Osmania University, Hyderabad, Deccan. |
| 15-9-1931 | R | Dasannacharya, (B.), Ph.D, Professor of Physics, Benares Hindu University, Benares. |
| 17-4-1931 | R | Deodhar, (D.B), Ph.D, Reader, Physics Department, Lucknow University, Lucknow. |
| 17-4-1931 | R | Dey, (P.K.), M Sc, I.A.S., Plant Pathologist to Government, United Provinces, Nawabganj, Cawnpore. |
| 29-2-1932 | R | Deb, Suresh Chandra, D.Sc., Physics Department, Allahabad University, Allahabad. |
| 1-1-1930 | R* | Dhar, (N.R.), D.Sc, Docteur ès Sciences, F.I.C., Professor of Chemistry, Allahabad University, Allahabad. |
| 1-1-1930 | R* | Drane, (H.D.H.), M.Sc., Ph.D., A.M I.E.E., A M.I. Chem. E., Principal, Harcourt Butler Technological Institute, Cawnpore. |
| 17-4-1931 | R | Dudgeon, (W.), Ph.D., Ewing Christian College, Allahabad. |
| 19-3-1931 | R | Dutt, (S.K.), M.Sc., Zoology Department, Allahabad University, Allahabad. |
| 17-4-1931 | R | Dutt, (S B.), D.Sc., Reader, Chemistry Department, Allahabad University, Allahabad. |
| 28-10-1932 | R | Dutt, (A.K.), M.Sc, Benares Hindu University, Benares. |
| 17-4-1931 | R | Forman, (D.N.), M.D., Jumna Dispensary, Allahabad. |
| 22-2-1933 | R | Ghatak, Narendranath, M. Sc., Chemistry Department, Allahabad University, Allahabad. |
| 19-3-1931 | R | Ghosh, (R.N.), D Sc., Physics Department, Allahabad University, Allahabad |
| 19-3-1931 | R | Ghosh, Satyeshwar, D.Sc., Chemistry Department, Allahabad University, Allahabad. |
| 19-4-1931 | R | Ghosh, (B.N.), M Sc., St. Andrew's College, Gorakhpur. |
| 15-9-1931 | N | Gogate, (D.V.), M.A, Baroda College, Baroda. |
| 15-9-1931 | R | Gordon, (C.B.), B.A., Christ Church College, Cawnpore. |
| 17-4-1931 | R | Gupta, (B.M.), D.Sc., Deputy Public Analyst to Government, United Provinces, Lucknow. |
| 21-12-1931 | R | Hansen, (W.J)., M.A., Allahabad Agricultural Institute, Naini, E.I.R., Allahabad. |

F. 2

| Date of Election. | | Alphabetical List of Ordinary Members |
|---|---|---|
| 17-4-1931 | R | Higginbottom, Sam, D. Phil., Principal, Allahabad Agricultural Institute, Naini, E.I.R. (Allahabad). |
| 17-4-1931 | R* | Hunter, Robert (F.), D.Sc., Ph.D., Professor of Chemistry, Muslim University, Aligarh. |
| 21-12-1931 | R | Joshi, (S.S.), D.Sc., Professor of Chemistry, Benares Hindu University, Benares. |
| 15-9-1931 | N | Kichlu, (P.K.), D.Sc., Department of Physics, Government College, Lahore. |
| 1-1-1930 | R* | King, (C.A.), B.Sc., (Hons.) A.R.C.Sc., M.I.M.E, Principal, Engineering College, Benares Hindu University, Benares. |
| 17-4-1931 | R | Koshambi, (D.D.), M.A., Department of Mathematics, Muslim University, Aligarh. |
| 1-1-1930 | R* | Luxmi Narayan, D.Sc, Reader, Mathematics Deparment, Lucknow University, Lucknow. |
| 1-1-1930 | R* | MacMahon, (P.S.,) B.Sc. (Hons.), M.Sc. Professor of Chemistry, Lucknow University, Lucknow. |
| 1-1-1930 | R* | Mathur, (K.K.), B.Sc. (Hons.), A.R.S.M., Professor of Geology, Benares Hindu University, Benares. |
| 1-1-1930 | R* | Mehta, (K.C.), Ph.D., M.Sc., Agra College, Agra. |
| 1-1-1930 | R* | Mitter, (J.H.), M.Sc., Ph.D., Professor of Botany, Allahabad University, Allahabad. |
| 15-9-1931 | R | Mathur, (L.P.), M.Sc., St. John's College, Agra. |
| 19-3-1931 | R | Mazumdar, Kanakendu, D.Sc., Physics Department, Allahabad University, Allahabad. |
| 19-3-1931 | R* | Mehra, (H.R.), Ph.D., Reader, Zoology Department, Allahabad University, Allahabad. |
| 21-12-1931 | R | Mehta, (N.C.), I.C.S., Director of Agriculture, United Provinces, Lucknow. |
| 17-4-1931 | R | Mukerjee, (S.K.), M.Sc., Agra College, Agra. |
| 17-4-1931 | R | Mukerjee, (S.K.), D.Sc. Reader, Botany Department, Lucknow University, Lucknow. |
| 22-2-1933 | R | Narliker, (V. V.), M.A., Professor of Mathematics, Benares Hindu University, Benares. |
| 17-4-1931 | R | Nehru, (S S.), M.A, Ph.D., I.C.S., M.L.C, Deputy Secretary to Government, U. P., Publicity Department, Lucknow. |
| 17-4-1931 | R | Pandya, (K.C.), D.Sc, St. John's College, Agra |
| 3-4-1933 | N | Parija, (P. K.), M.A., I.E.S., Ravensha College, Cuttack. |
| 15-9-1931 | N | Prasad, Mata, D.Sc., Royal Institute of Science, Bombay. |
| 3-4-1933 | R | Prasad, Badrinath, Ph.D., Docteur ès Sciences, Mathematics Deptt., Allahabad University, Allahabad. |

| Date of Election. | | Alphabetical List of Ordinary Members |
|---|---|---|
| 17-4-1931 | R | Puri, (B D ), M A., Thomason Civil Engineering College, Roorkee. |
| 22-12-1932 | N | Qureshi, (M.), M.Sc., Ph.D., Professor of Chemistry, Osmania University College, Hyderabad, Deccan. |
| 3-4-1933 | R | Raja Ram, M.A., B.E., Principal of Civil Engineering, Thomason College, Roorkee, U. P. |
| 19-3-1931 | R | Ranjan, Shri, M.Sc., Docteur ès Sciences, Reader, Botany Department, Allahabad University, Allahabad. |
| 15-9-1931 | N | Rao, A. Subba, D.Sc Medical College, Mysore. |
| 22-2-1933 | N | Rao, G. Gopala, B.A , M.Sc., Chemistry Department, Andhra University, Waltair. |
| 21-12-1931 | R | Rao, D. H. Ramchandra, B.E., A.M.I.E., Engineer, Allahabad University, Allahabad. |
| 22-2-1933 | N | Ray, Bidhubhusan, D.Sc., 92 Upper Circular Road, Calcutta. |
| 21-12-1931 | R | Ray, Satyendra Nath, M.Sc., Physics Department, Lucknow University, Lucknow. |
| 1-1-1930 | R* | Richards, (P.B)., A.R.C.S., F.E.S., Entomologist to the Government, United Provinces, Cawnpore. |
| 1-1-1930 | R* | Saha, (M.N.), D.Sc , F.R S., F.A.S.B., F. Inst. P., P.R.S., Professor of Physics, Allahabad University, Allahabad. |
| 29-2-1932 | R | Saha, Jogendra Mohan , M.Sc., Manager, Srikrishna Desi Sugar Works, Jhusi, (Allahabad). |
| 1-1-1930 | R* | Sahni, (B.), D.Sc., Sc.D., F.L.S., F.A.S.B., Professor of Botany, Lucknow University, Lucknow. |
| 17-4-1931 | R* | Samuel, Rudolf, Ph.D., Professor of Physics, Muslim University, Aligarh. |
| 17-4-1931 | R | Sane, (S.M.), B.Sc., Ph.D., Reader, Chemistry Department, Lucknow University, Badshah Bagh, Lucknow. |
| 21-12-1931 | R | Sathe, (J.L)., I.C.S., Finance Secretary to Government, U. P., No. 1, Secretariat Quarters, Lucknow. |
| 3-4-1933 | R | Sen, (K. C.), D.Sc., Imperial Institute of Veterinary Research, Muktesar, Kumaun. |
| 17-4-1931 | R | Seth, (S.D.), M.Sc., Christ Church College, Cawnpore. |
| 1-1-1930 | R* | Sethi, (R.L.), M.Sc., M.R.A.S., Economic Botanist to Government, United Provinces, Cawnpore. |
| 19-3-1931 | R | Sethi, Nihal Karan, D.Sc., Agra College, Agra. |
| 15-9-1931 | R | Sharma, Ram Kishore, M.Sc., Physics Department, Ewing Christian College, Allahabad. |
| 3-4-1933 | N | Siddiqi, (M. R)., Ph.D., Professor of Mathematics, Osmania University, Hyderabad, Deccan. |

| Date of Election | | Alphabetical List of Ordinary Members |
|---|---|---|
| 3-4-1933 | R | Siddiqui, Mohd. Abdul Hamid, M. B. B. S., M. S., F. R. C. S., D. L. O., Professor of Anatomy, King George's Medical College, Lucknow. |
| 17-4-1931 | R | Singh, Avadesh Narain, D.Sc , Department of Mathematics, Lucknow University, Lucknow. |
| 17-4-1931 | N | Soonawala, (M. F.), M.Sc., Maharaja's College, Jaipur (Rajputana). |
| 19-3-1931 | R* | Srivastava, (P. L.), M.A., D.Phil., Reader, Mathematics Department, Allahabad University, Allahabad. |
| 15-9-1931 | N | Srikantia, (C.), B.A., D.Sc., Medical College, Mysore. |
| 24-1-1933 | N | Subramanian, (S.), M.A., Mathematics Department, Annamalai University, Annamalainagar P. O., South India. |
| 17-4-1931 | R | Sulaiman, (S.M.), Hon'ble Sir., Chief Justice, High Court, Allahabad. |
| 19-3-1931 | R | Taimini, Iqbal Kishen, Ph.D., Chemistry Department, Allahabad University, Allahabad. |
| 19-3-1931 | R | Tewari, Shri Govind, M.A., Mathematics Department, Allahabad University, Allahabad. |
| 3-4-1933 | R | Thompson, (C. D.), M. A., Professor of Economics, Allahabad University. |
| 19-3-1931 | R | Toshniwal, (G.R.), M.Sc., Physics Department, Allahabad University, Allahabad. |
| 19-3-1931 | N* | Vijayaraghavan, (T), D.Phil., Reader, Mathematics Department, Dacca University, Ramna, Dacca. |
| 1-1-1930 | R* | Wali Muhammad, Ch., M.A., Ph.D., I.E.S., Professor of Physics, Lucknow University, Lucknow. |
| 15-9-1931 | R | Wall, (W. G. P.), M.Sc., I.E.S., Associate I.E.E., M.R.S.T., Inspector of Schools, Allahabad Division, Allahabad. |
| 1-1-1930 | N* | Weil, Andre, Docteur ès Sciences, 3, Rue Auguste, Comte, Paris (6c), France. |

N.B.—The Secretaries will be highly obliged if the members will kindly bring to their notice errors, if there be any, in their titles, degrees, and addresses.

# LIST OF MEMBERS OF THE PUBLICATION COMMITTEES

## Mathematics.

1. Prof. A. C. Banerji, M. A., M. Sc., F. R. A. S., I. E. S., Professor of Mathematics, Allahabad University, Allahabad.
2. Prof. André Weil, Docteur ès Sciences (Paris), 3 Rue Auguste, Comte. Paris (6e) France.

## Physics.

3. Prof. M. N. Saha, F. R. S., D. Sc, Professor of Physics, University of Allahabad, Allahabad.
4. Prof. Ch. Wali Mohammad, M. A., Ph. D., I. E. S., Professor of Physics, Lucknow University, Lucknow.

## Chemistry.

5. Prof. N. R. Dhar, D. Sc., I. E. S., Professor of Chemistry, University of Allahabad, Allahabad.
6. Prof. P. S. MacMahon, B. Sc., M. Sc, Professor of Chemistry, Lucknow University, Lucknow.

## Zoology.

7. Prof. D. R. Bhattacharya, D. Sc., Ph. D., Professor of Zoology, University of Allahabad, Allahabad.
8. Prof. K. N. Bahl, D. Phil., D. Sc., Professor of Zoology, Lucknow University, Lucknow.

## Botany.

9. Prof. B. Sahni, D. Sc., Sc. D , F. L. S., F. A. S. B., Professor of Botany, Lucknow University, Lucknow.
10. Prof. K. C. Mehta, Ph. D., M. Sc., Professor of Botany, Agra College, Agra.

## Mining and Geology.

11. Prof. K. K. Mathur, B. Sc., A. R. S. M., Professor of Geology, Benares Hindu University, Benares.

## Agriculture.

12. Prof. C. Maya Das, M. A., B. Sc., I. A. S., Principal, Agricultural College, Cawnpore.
13. Dr. Sam Higginbottom, Principal, Agricultural Institute, Naini. (Allahabad).

# LIST OF EXCHANGE JOURNALS

| Journals | Publishers |
|---|---|
| 1. The Bell System Technical Journal ... | The American Telephone and Telegraph Coy., New York, (U.S.A.). |
| 2. Physics in Meteorology ... | ... The Institute of Physics, Exhibition Road, London. |
| 3. Proceedings of the Imperial Academy | Imperial Academy, Ueno Park, Tokyo, (Japan). |
| 4. Journal of the Franklin Institute ... | The Franklin Institute of the State of Pennsylvania, Philadelphia, (U.S.A.). |
| 5. Bell Telephone System. (Technical Publications). | The Bell Laboratories, New York, (U.S.A.) |
| 6. Collected Researches . ... | The National Physical Laboratory, Teddington, Middlesex, England. |
| 7. Proceedings of the Cambridge Philosophical Society. | The Philosophical Society, Cambridge, England. |
| 8. Proceedings of the Royal Society of Edinburgh. | The Royal Society of Edinburgh, England. |
| 9. Proceedings of the Indian Association for Cultivation of Science. | The Indian Association for Cultivation of Science, Calcutta. |
| 10. Science Notes. and Memoirs ... | Indian Meteorological Department, Poona 5. |
| 11. Bulletin of the Patna Science College Philosophical Society. | The Patna Science College Philosophical Society, Patna. |
| 12. Journal of the Indian Institute of Science. | The Indian Institute of Science, Bangalore. |
| 13. Current Science ... .... | Ditto |
| 14. Transactions of the Royal Society of Canada. | The Royal Society of Canada, Ottawa, Canada. |
| 15. Journal of the Royal Astronomical Society of Canada. | The Royal Astronomical Society of Canada, Toronto, Canada. |
| 16. Publications of the Dominion Astrophysical Observatory. | The Dominion Astrophysical Observatory, Victoria, Canada. |
| 17. Dominion of Canada National Research Council Report. | Ditto |

| Journals | Publishers |
|---|---|
| 18. Proceedings of the Royal Society of Victoria. | The Royal Society of Victoria, Melbourne C. I., Australia. |
| 19. Journal and Proceedings of the Royal Society of New South Wales. | The Royal Society of New South Wales, Sydney, Australia. |
| 20. Transactions and Proceedings of the New Zealand Institute. | The New Zealand Institute, Wellington, New Zealand. |
| 21. Publications of the Observatory of the University of Michigan. | The Observatory, University of Michigan, Michigan. (U. S. A.) |
| 22. Lick Observatory Bulletin .. | The Lick Observatory, Mount Hamilton, Berkeley, California, (U.S A.). |
| 23. Proceedings of the American Academy of Arts and Sciences. | The American Academy of Arts and Sciences, Boston, (U.S A.) |
| 24. Memoirs of the American Academy of Arts and Sciences. | Ditto |
| 25. Journal of Mathematics and Physics .. | Massachusetts Institute of Technology, Cambridge, Mass. (U. S. A.) |
| 26. Year Book 1930 ... ... | Academy of Natural Sciences, Philadelphia, (U. S. A.) |
| 27. Proceedings of the Academy of Natural Sciences of Philadelphia. | Ditto |
| 28. "Bureau of Standards" Journal of Research. | Department Commerce, Bureau of Standards, Washington, (U. S. A.). |
| 29. Contributions from Mount Wilson Observatory. | The Mount Wilson Observatory, Pasadena, California, (U. S. A.). |
| 30. Communications ... | Ditto |
| 31. Annual Report of the Director of the Mount Wilson Observatory. | Ditto |
| 32. Anzeiger (Mathematis and Science) | Akademie der Wissenschaften, Vienna, Austria. |
| 33. Almanach ... ... ... | Ditto |
| 34. Anzeiger (Philosophy and History) ... | Ditto |
| 35. Bulletin de La Classe Des Sciences ... | The Academie Royale de Belgique, Brussels, Belgium. |
| 36. Mathematische Und Naturwissenschaftliche Berichte Ana Ungaru. | Ungarische Akademie der Wissenschaft, Budapest, Hungary. |
| 37. Sitzungsberichte Der Preussischen Akademie. | Preussischen Akademie der Wissenschaften, Berlin, Germany. |
| 38. Berichte Der Deutschen Chemischen Gesellschaft. | Deutsche Chemische Gesellschaft, Berlin, Germany. |

| Journals | Publishers |
|---|---|
| 39 Nachrichten Von der Gesellschaft der Wissenschaften Zu Göttingen. Mathematisch-Physikalische Klasse. | Gesellschaft der Wissenschaften Zu Göttingen, Germany. |
| 40. Geschaftliche Mitteilungen. ... | Ditto |
| 41. Mathematische Naturwissenschaftliche Klasse. | Bibliothekar, Heidelberger Akademie der Wissenschaften, Heidelberg, Germany. |
| 42. Communications from the Physical Laboratory, Leiden. | The Physical Laboratory, Leiden, Holland. |
| 43. Science Report of the Tohoku Imperial University. | Imperial University of Tohoku, Sendai, Japan. |
| 44. Proceedings of the Physico-Mathematical Society of Japan. | The Physico-Mathematical Society of Japan, Tokyo, Japan. |
| 45. The Keijo Journal of Medicine ... | The Medical Faculty, Keijo Imperial University, Chosen, Japan. |
| 46. Journal Du Cycle de Physique et De Chemie. | Academie des Sciences D'Ukraine, Kyiv, Ukraine. |
| 47. Journal Du Cycle Mathematique ... | Ditto |
| 48. Bulletin dela classe des Sciences Physique et Mathematiques. | Ditto |
| 49. Physikalische Zeitschrift Der Sowjetunion. | Physical Journal of the Soviet Union, Kharkov, Chikovsakaya 16, Soviet-Russia. |
| 50. Geographical and Biological studies of Anopheles Maculipennis in Sweden. | Kungliga Svenska Vetenskapsakademie, Stockholm, Sweden. |
| 51. Kungl. Fysiografiska Sällskapets Forhandlingar. | Universitet, Lund, Sweden. |
| 52. Uppsala Universitets Arsskrift ... | Universitet, Uppsala, Sweden. |
| 53. Fifty years Retrospect, (Anniversary Volume 1882-1932). | The Royal Society of Canada, Ottawa, Canada. |

# LIST OF PAPERS READ BEFORE THE ACADEMY OF SCIENCES DURING THE PERIOD APRIL 1932 TO MARCH 1933

1. On the absorption spectrum of $SO_3$, and heat of dissociation of $O_x$ : by Arun Kumar Dutta, M. Sc., Physics Deptt., Allahabad University.

2. On the absorption spectrum of $N_2O$, and heat of dissociation of $N_2$ : by Arun Kumar Dutta, M.Sc., Physics Deptt., Allahabad University, Allahabad.

3. On the Quantitative study of the absorption spectra of HBr and HI : by Arun Kumar Dutta, M.Sc, Physics Deptt., Allahabad University, Allahabad.

4. On the singularities of Laplace-Abel Integral : by Dr. P. L. Srivastava and S. P. Jain, M. Sc., Mathematics Deptt., Allahabad University, Allahabad.

5. On the phenomenon of after-effect and induction period in the reversible photochemical reduction of Tungstic acid Sol : by Dr. S. Ghosh, D.Sc. and Dr. A. K. Bhattacharya, D.Sc., Chemistry Deptt., Allahabad University, Allahabad.

6. On a generalisation of the second theorem of Bour Baki : by Prof. D.D. Kosambi, Muslim University, Aligarh.

7. On a generalised formulation of Trouton's Law : by Satyendra Nath Ray, M.Sc., Lecturer in Physics, Lucknow University, Lucknow.

8. A Generalisation of a well-known theorem (Vivanti-Borel-Dienes theorem) : by Dr. T. Vijayaraghavan, D. Phil., Reader in Mathematics, Dacca University, Ramna. (Dacca).

9. On the absorption spectrum of some higher oxides : by A. K. Dutt, M. Sc., Physics Deptt., Allahabad University, Allahabad.

10. Post-dissociation radiation from $SO_3$ : by A. K. Dutta, M. Sc., Physics Deptt , Allahabad University, Allahabad.

11. Absorption spectrum of Irradiated Iodine : by G. R. Toshniwal, M.Sc. Physics Deptt., Allahabad University, Allahabad.

12. Classification of the spectral lines of $Cl_{iv}$ and $Cl_v$ : by Suresh Chandra Dev, M. Sc., Physics Deptt., Allahabad University, Allahabad.

13. On two species of the genus Cephalogonimus Poirier from water tortoises of Allahabad with remarks on the family Cephalogonimidae Nicoll : by Bindeshri Prasad Pande, M. Sc., Zoology Deptt., Allahabad University, Allahabad.

14. A note on the Expanding Universe : by Prof A. C. Banerji, I. E. S., Professor of Mathematics, Allahabad University, Allahabad.

16a

15. On some experiments with Iodine Vapour : by G. R. Toshniwal, M.Sc., Physics Deptt., Allahabad University, Allahabad.

16. Ageing of ferric phosphate and vanadium pentoxide Sols. at various temperatures: by Dr. S Ghosh, D. Sc., and S. N. Banerji, Chemistry Deptt., Allahabad University, Allahabad.

17. On the absorption spectra of Alkyl Halides: by Prabhat K. Sen Gupta, M. Sc., Physics Deptt, Allahabad University, Allahabad.

18. On the (i) Virtual Independence of the Reverberation period in Architectural Acoustics of the Auditorium Volume, and (ii) its Dependence on sound Frequency. : by Satyendra Nath Ray, M. Sc., Lecturer in Physics, Lucknow University, Lucknow.

19. On the Equation of state of saturated vapour : by Messrs. Brij Bhusan Kak and Sushil Kumar Ghosh, Physics Deptt.. Lucknow University, Lucknow.

20. On the relation between energy current incident on an Auditorium Wall and Gauss's Theorem : by Satyendra Nath Ray, M. Sc., Lecturer in Physics, Lucknow University, Lucknow.

21. On the formula for the Locus of discontinuities in the Isothermals of Brombenzol : by Gopal Das Kshetrapal, Physics Deptt., Lucknow University, Lucknow.

22. On some expansions and integrals involving the Parabolic cylinder functions : by V. L. Mutatker, M. Sc., Mathematics Deptt., Allahabad University, Allahabad.

23. Chemical Examination of the Seeds of *Thevetia neriifolia* (Juss), part I. : by Narendra Nath Ghatak, M. Sc., Chemistry Deptt., Allahabad University, Allahabad.

24. On the determination of the Vapour pressure of Zinc Bromide : by M. S Desai, M. Sc., Physics Deptt., Allahabad University, Allahabad.

25. A note on special theory of Relativity : by Prof. A. C. Banerji, I. E. S., Professor of Mathematics, Allahabad University, Allahabad.

26. Spectra of trebly and quadruply Ionised lead. : by Jai Kishen, Physics Deptt, S. D. College, Lahore.

27. On an Echinostome Cercaria-Cercaria Palustris with notes on its Life-History: by R. C. Chatterjee, M.Sc, Helminthological Institue, University of Rangoon, Rangoon.

28. On an Experimental Determination of the Law of Variation of the Avogadro's number with Hofmann's Vapour Density apparatus: by Miss A. K. Cheriyan and P. I. Abraham, Lucknow University, Lucknow.

29. An extension of a result in the Factorial Series : by S. P. Jain, M. Sc., Mathematics Deptt., Allahabad University, Allahabad.

30. Chemical examination of the fruits of *Tribulus terrestris*, Linn.: by Narendra nath Ghatak, M. Sc., Chemistry Deptt., Allahabad University, Allahabad.

31. Conclusion on the Strength and the Nature of Binding from the continuous absorption spectrum : by Dr. Frank and Dr. Kuhn, Göttingen.

32. An X-ray Investigation of the crystals of Diphenyl Nitrosoamine: by Mata Prasad and S. G. Khubchandani, The Royal Institute of Science, Bombay.

33. Influence of temperature and light intensity on photosynthesis and respiration and an explanation of the phenomena of 'Compensation point' and 'Solarisation'. : by Dr. N. R. Dhar, D. Sc., I. E. S., Professor of Chemistry, Allahabad University, Allahabad.

34. Peroxydase from the fruits of *Tribulus terrestris* (Linn). : by Narendranath Ghatak and K. Venkata Giri, M. Sc., Chemistry Deptt., Allahabad University, Allahabad.

35. Normal frequency spectra. : by J. S. Badami, Pundoli Pol, Surat.

36. Absorption spectra of some Halogen derivatives of Methane. : by N. K Saha, M. Sc, Deptt. of Physics, Allahabad University, Allahabad.

37. A class of Dirichlet's Series possessing essential characteristics of a Taylor's Series. : by Dr. P. L. Srivastava, M. A., D. Phil., Reader in Mathematics, Allahabad University, Allahabad.

38 On an infinite series of integrals involving Sturm-Liouville Eigen functions. : by Dr M. Raziuddin Siddiqi, M. A. (Cantab), Ph. D. (Leipzig), Deptt. of Mathematics, Osmania University College, Hyderabad, Deccan.

39. On the maximum modulus principle. : by Dr. P. L Srivastava, M. A., D. Phil., and S. P. Jain, M Sc., Mathematics Deptt. Allahabad University, Allahabad.

40. New Blood-flukes of the family Spirorchidae Stunkard from North Indian Fresh-water Tortoises, by Dr H. R Mehra, Ph. D , Reader, Zoology Deptt, Allahabad University, Allahabad

41. Studies on the effect of phosphates on the respiration of green leaves in (1) Allium tuberosum (2) Eugenia jambolana. : by U. N Chatterjee, M. Sc., Botany Deptt., Allahabad University, Allahabad.

## JOURNALS SUBSCRIBED BY THE ACADEMY OF SCIENCES, U. P. DURING THE YEAR 1932

### PHYSICS

1. Die Naturwissenschaften. (Berlin) 20. Jahrgang.
2. Zeitschrift fur Astrophysik. Band 5.

*Financial Statement from 1st January to 31st December, 1932.*

## Receipts.

| | Rs. | as. | p. |
|---|---|---|---|
| Opening balance on 1st January 1932. | 13 | 11 | 6 |
| Bank balance on 1st January 1932. | 2,351 | 8 | 0 |
| Government Grant (Non-recurring). | 2,000 | 0 | 0 |
| *Membership Fee :—* | | | |
| Resident membership fee. Rs. 710/ | | | |
| Non-resident " 145/ | | | |
| Part payment of subscription for 1932 5/ | | | |
| Resident membership fee 1933. 15/ | 875 | 0 | 0 |
| Advertisement charges in the Bulletin Vol. 1, 1931-32 | 15 | 0 | 0 |
| Building Fund Donation | 66 | 0 | 0 |
| Receipt of postage stamps transferred from postage account register on 31st December, 1932. | 2 | 5 | 3 |
| **Total Rupees** | 5,323 | 8 | 9 |

## Expenditure.

| | Rs. | as. | p. |
|---|---|---|---|
| Establishment | 622 | 7 | 0 |
| Contingency. (Including printing, postage stamps and stationery). | 365 | 0 | 0 |
| Bank Charges on outstation cheques.. | 4 | 12 | 6 |
| Journals for 1931 | 63 | 12 | 0 |
| Binding of journal | 3 | 8 | 6 |
| Printing of Bulletin for 1931 | 1,293 | 4 | 6 |
| Printing of Bulletin Vol. 2, No. 1, 1932 | 369 | 0 | 0 |
| One Duplicator machine... | 168 | 0 | 0 |
| Cash in hand... | 8 | 12 | 3 |
| Building Fund Rs. 66/ | | | |
| **Balance in Bank Rs. 2,359/0/6... | | | |
| *Bank balance :—* | 2,425 | 0 | 6 |
| **Total Rupees** | 5,323 | 8 | 9 |

| | Rs. | as. | p. |
|---|---|---|---|
| **Printing charges of Bulletin Vol. 2, Nos. 2, 3 and 4. | 1,015 | 0 | 0 |
| Binding of journals. | 96 | 8 | 0 |
| Journals. | 650 | 0 | 0 |
| Contingency. | 165 | 0 | 0 |
| Furniture, | 45 | 0 | 0 |
| Balance. | 387 | 8 | 6 |
| | 2,359 | 0 | 6 |

D. R. BHATTACHARYA, D.Sc., Ph. D., F. Z. S.

*Hony. Treasurer.*

The Academy of Sciences of the United Provinces of Agra and Oudh.

# PRESIDENT'S ADDRESS

## ADDRESS OF THE PRESIDENT, PROFESSOR M. N. SAHA, AT THE ANNIVERSARY MEETING HELD ON JANUARY 13, 1933.

THE HON'BLE THE MINISTER OF EDUCATION, FELLOWS AND MEMBERS OF THE ACADEMY, LADIES AND GENTLEMEN,—Before rising to address you at the Anniversary Meeting, as President of the Academy, I wish to read to you a message which His Excellency Sir William Malcolm Hailey, the Patron of the Academy, has graciously sent to us on the occasion of the second anniversary, which is as follows:—

### Message from His Excellency Sir W. Malcolm Hailey, the Patron of the Academy.

*I am glad to know that the Academy of Sciences has now safely terminated its second year and is holding its annual meeting on the 13th of January. I am convinced that it is doing good work in co-ordinating scientific effort in this Province, and it performs moreover an important function in bringing before the public the achievements of our scientists. We all hope that a time will come when the Indian public will realise the need for supporting scientific research; apart from other grounds, it would help to gain for India some of the position she hopes to occupy among other nations if she could produce a strong band of scientists whose names were recognized in the great academies of the world. We can only secure public interest in science and scientific workers by some advertisement of their efforts, and it is to my mind quite legitimate that the Academy of Sciences should include this among its activities.*

<div align="right">

*(Sd.)  W. M. Hailey*

*Governor*

*United Provinces*

</div>

*9th January, 1933*

On your behalf I wish to convey to His Excellency our respectful thanks for these kind words of encouragement. His Excellency's interest and affection for the Academy is well known to the members, and it is a pleasure to find that amidst the burdens of the government he has found time to send us a message of hope and encouragement. We hope that in the years to come we shall be able to render to the community the ideals which he set before us in his last year's address which I again take the liberty of quoting:—" I am confident that in due season you will

see your society occupy an important place in the intellectual life of the Province, originating enquiry, co-ordinating scientific research, and pooling the results."

In this connection I wish to invite the attention of the present audience to another pleasant side of His Excellency's activities, *viz.*, to the great interest he is taking in the industrialisation of these Provinces. You are all aware that, taking advantage of the protective tariff imposed by the Government of India on imported sugar, a large number of factories is being started, and so far these Provinces are fortunately having the lion's share. His Excellency has been taking a most lively interest in the starting of these industries, and he has never refused the request of any party to preside at their inauguration ceremonies. This has stimulated the multiplication of factories, and probably His Excellency's services in this connection will be long gratefully remembered when the country settles down to a calmer mood and derives the full benefit of this industrialisation. The future years promise to be fat years ; but in this connection I wish to invite the attention of the industrialists of the very wise counsel given by His Excellency, particularly regarding the advisability of having a co-operative research institute for improving the production and for greater utilisation of the by-products—for, after the fat years, a period of "lean years" is sure to come, when the tariff will be reduced, and competition from other provinces which are now backward in sugar production will be increasingly felt. In these "lean years" which I foresee, adoption of improved methods and utilisation of by-products will enable the factories to tide over the apprehended difficulties. Such research institutes exist in all countries; in this Province they may be organised if the sugar-growers combine and lay aside a small fraction of their income for financing the proposed research association.

My next pleasant duty is to accord a hearty welcome, on your behalf, to the Hon'ble Mr. J. P. Srivastava, M.Sc. Minister of Education in our Provinces and Honorary Fellow of our Academy, who has kindly consented to preside over our annual function. He is an extremely busy man, having to bear the heavy burden of a great administrative department on his shoulders. It was very kind of him to have found time to come to this meeting and encourage us by his presence, guidance, and advice. Himself a graduate in science and an alumnus of the Allahabad University he has been a pioneer and captain of industries in these Provinces, and thus forms a connecting link between science as taught in the universities and its application to the economic life of the country. We expect that he will watch the growth of the Academy in the years to come with loving care and affection.

I am sorry that in the second year of our existence we have to deplore the loss, by death, of two of our most esteemed colleagues. The death of Mr. Nabendu Bhusan Banerji, M.Sc., late of the Indian Railway Service, at the early age of 29, removes from our midst a very promising recruit to the Railways, and a prospective scientific worker. His life was so short that the public had no time to be aware of his great promise. He was a son of the late Dr. Satish Chandra

Banerji, one of the legal luminaries of these Provinces during the last generation. N. B. Banerjee was one of my early batch of students at the Physical Laboratory of the Allahabad University. After a brilliant career in the University he entered, much against his will, the Railway service by open competition. His dislike to; the service, as in the case of many other young men of high intellectual capacity was due to his inclination to lead a life of scholarship and of devoted service to science; but, alas! pure science offers so few avenues of existence in our country that a large number of promising young men can exercise no discretion in the choice of their career. Accepting his position with philosophic resignation he tried to apply his scientific training to the elucidation of problems of transport and rates – subjects of national importance in which there are very few experts in this country. He had made considerable progress in this line when his life was cut short by a disease which could not be diagnosed.

In the untimely death of Dr. Dudgeon, at the early age of 46, the Academy has lost one of its most esteemed members, and many of us a personal friend. Dr. Dudgeon was born and educated in America, and was sent to India by the American Mission in 1917 as Professor of Biology in the Ewing Christian College, Allahabad. He made India his home, and became Indian in his sympathies and took a prominent part in the educational life of the country. His contributions to Botany are many and varied; and, as a part-time teacher in the University, he had under him a number of students doing original work in Botany, one of whom was recently awarded the D.Sc. degree. As a mark of recognition of his contributions he was elected President of the Botanical Section of the Science Congress in 1922 and first President of the Indian Botanical Society in 1921. He has been recently on a visit to America, and fell a victim to influenza. The news of his death came as great shock to his numerous friends and admirers at Allahabad, many of whom have been recipients of a Christmas card from him simultaneously with the news of his death. A fuller description of his scientific work will be published later.

We are still an infant body, as we are now entering on the third year of our existence. It will be profitable to recall some of our activities during the last session. Last year we published one *Bulletin* in course of the whole year. This year we are publishing four numbers, of which the first two are already out. You will notice that we have effected considerable improvement in printing and get-up and now our publications rank with the best in the world. Our thanks are due to Dr. S. C. Deb, who has so far looked after the publication of the *Bulletin*. We have also made arrangements that papers published in the *Bulletin* should be regularly abstracted in the Science Abstracts, "Physikalische Berichte," and other abstracts. I am glad to announce that we have been able to exchange our *Bulletin* with publications of most of the learned societies of the world. A full list of such journals is published regularly in the *Bulletin*. In this connection we are extremely grateful to Sir Richard Gregory, the Editor of the *Nature*, who has given a very kindly and sympathetic review of the inaugural ceremony of the Academy in his

well-known journal. Sir Richard Gregory has been a friend of scientists all over the world, particularly to Indian scientists, and I hope he will be accorded a hearty welcome by all scientific workers when he comes to Allahabad, as he has informed me, for a short tour in course of the current month. When he is here I hope we shall be able to convince him of the necessity of having a *Bulletin* for our Society.

Before proceeding to my address I wish to remind you that this is the last year of my Presidentship. I wish to introduce to you my successor, Dr. K. N. Bahl, D.Sc., Professor of Zoology in the Lucknow University. He is a distinguished educationist, and a biologist of great eminence. He has been associated with us in the starting of the Academy from its very embryonic stage, and I hope that under his guidance the Academy will regain fresh vigour and life, and will prove itself more useful to the public. I wish also to express my thanks and my feelings of gratitude to the gentlemen who constituted the council last year. I am particularly indebted to my friends, Professors MacMohan and A. C. Banerjee, for cordial co-operation and hearty assistance. They have given the Academy ungrudgingly their most valued time and service, and, without their loyal co-operation, it would have been impossible to achieve what little we have done.

I now proceed to my address :—

## The Present Crisis in Dynamics

In my inaugural address last year I dealt mainly with the value of science to human life. In the present address I wish to deal with a more technical topic, *viz.*, with the present crisis in the science of dynamics. I have chosen this subject for a variety of reasons. As you are all aware the world is now passing through a great crisis. The mid-Victorian period of hope and faith in evolutionary progress has given place to one of distrust and uncertainty regarding the future. The world is not moving onwards, but according to many competent observers it seems to be moving backwards. In his address to the Academy last year His Excellency referred to this spirit of distrust amongst individuals, communities and nations which is leading to the present world-chaos and put to us the query whether science can assist us in securing a more rational manipulation of human passions ? As a scientist I would submit the main lesson which science teaches us is that every question should be studied *objectively*, and politics and economics form no exception to this rule. There is, unfortunately in this country, no organisation where data about these questions can be collected and examined dispassionately. On the other hand, these topics are being discussed by different parties in a subjective and almost obscurantist fashion, leading to muddling of issues and production of much heat that can be avoided. However, I do not wish to abuse the prerogative of the politician, and in this gathering of scientific men I would like to discuss a crisis through which the science of physics is passing at the present time. It may interest my political friends who have kindly come here

to know that the science of physics is also passing through a great crisis. As you may be aware, the word physics is derived from a Greek word "physis," which means Nature. The scope of physics is the study of Nature, her phenomena and discovery of the laws behind all these phenomena. These studies are not new, but thousands of years can be recounted which mankind has spent in these studies. The chief task before man has been to increase his experience by making observation and new experiments, and then trying to transfer his results and impressions from the world of perception to his mind, and form a mental picture of the whole process; unless he can perform this task satisfactorily he will have no means of storing his experiences, acquainting his fellow-men with his achievements and transmitting them to posterity. The science of mathematics originated as a short-hand process for recording human experience. But it developed a method, a personality and a life-process of its own, and in its mature growth, it has been found not only useful for recording human experience, but has also very often suggested new paths of knowledge.

A famous writer who is himself a mathematician humorously remarked that the Creator must have been a mathematician. The remark is by no means an exaggeration, though it is safer for scientific men not to indulge in the dubious interpretation of the Divine Will.


## Ancient Nations had no Dynamics

To be able to appreciate the present crisis I would ask you to go back over two thousand years, to the old cultural world of the Greek and Hindu savants. One point will at once strike you —The sciences created or inherited by these old people were all static, e.g, geometry, algebra, trigonometry and arithmetic; they had no science to describe motion. Yet we all know that Nature is full of motion. Even phenomena which are apparently static are found on closer scrutiny to consist of latent motion. Witness, for example, the alternation of the day and night all over the world which was a puzzle to ancient people, but which is very simply explained as being due to the rotation of the earth round its axis; or again, take the phenomena of heat, which apparently betray no sign of motion, but science has taught us that it is due to the motion of myriads of molecules which constitute the material body. But though the ancients were conscious of the necessity of having a science of motion, and seemed to have bestowed much thought on it, they encountered immense difficulties in arriving at the correct principles –in fact, it is not much exaggeration to say that they never got anywhere near them: their vague and fruitless speculations are recorded in the problems raised by Zeno the Eleatic over Achilles and the Tortoise, the Stade and the Arrow, and so forth. The chief problem in motion is to define the space-time relationships of particles of matter and compare them with facts of experience. What Zeno meant by his famous paradoxes is

not yet clear. He is supposed, according to some authorities, to have refuted the reality of motion. If that be so, he must be reckoned as one of the greatest humbugs that ever lived. Others claim that Zeno had no such intention; he used the undisputed reality of motion to demonstrate the contradictions which are inherent in our mental picture of space, time and continuity. If this were his intention he must be regarded as a great thinker.

## Birth of the Science of Dynamics

Anyhow, the problem made no further progress till Galileo appeared on the scene two thousand years later. This philosopher, when old and almost blind, and deprived of movement by an intolerant clergy within the four walls of a castle which served as his prison, gave us the first solution of the problem of motion. They are now well known to the students of science as the Galileo-Newton laws of motion. Briefly speaking, he gave a precise mathematical meaning to the terms 'mass,' 'force,' 'acceleration,' and 'velocity' which are now used in dynamics, and expressed the relations amongst these quantities in the form of algebraic equations. The invention of infinitesimal calculus shortly afterwards by Newton and Leibnitz provided a very powerful language for expressing these ideas, and for rapidly operating with them—a quality which was lacking in the older algebra.

## Epistemological Objections to the Galilean Formulation of Dynamics

It is well known that in the sphere of physics and astronomy the science of dynamics met with all but unlimited success which made it difficult for the ordinary man to appreciate the logical difficulties which were raised to these principles by men like Bishop Berkeley, David Hume and other metaphysicians dealing with the theory of knowledge. They objected to the way in which physicists proposed to transfer events from the world of perception to the physicist's world-picture, and argued that in this process the human mind, which is the chief interpreter, has been altogether ignored, a procedure which Berkeley in particular considered illogical.

Berkeley taught that the qualities ascribed to matter like mass and extension are not inherent in it, but they are largely the creations of the human mind (intellectual constructions); hence they could not represent facts. His arguments, though brilliant, were rather exacting and even old, experienced men could not grasp his idea, and made jests about it. "What is matter? Never mind. What is mind ? No matter." Even long after his death Byron lampooned him in these verses:—

When Bishop Berkeley said " there was no matter "
And proved it—'twas no matter what he said.
They say his system 'tis vain to batter
Too subtle for the airiest human head;

And yet, who can believe it? I would shatter
Gladly all matters down to stone or lead
Or adamant, to find the world a spirit,
And wear my head, denying that I wear it.

But Berkeley was wiser than Byron ever thought of him. To-day the idea that in the analysis of the world, the human mind cannot be left out does *not* appear to be ludicrous.

We find, after all, that the way in which we have ascribed qualities to matter or created our space-time conceptions to represent motion are faulty, tainted by the limitations of the human mind.

## Triumphs of Dynamics

For 350 years mankind has been fascinated by the success of the science of dynamics in interpreting world phenomena, and why should it not be? For the success of dynamics was not only confined to the complete explanation of the mysterious motions of planetary bodies which fascinated the sages of the ancient world – who in these motions saw the hand of Providence writing out Destiny of men and nations, but in course of three centuries subsequent to Newton this science was destined to win fresh laurels in other fields. For physics found that all sensible phenomena by which we derive our conception of the world are in reality resolvable into so many motions of the matter by which it pushes against our senses of perception. Sound is vibration of air-masses, light even a few years back was supposed to be due to vibrations of Aether (it has not yet ceased to be vibrations), heat is resolvable into the chaotic motion of molecules and atoms, and colour depends on the number of vibrations of waves of light affecting our retina. What else is left of the inorganic world? Electricity at once comes into our mind. But physics found at the end of the last century that electricity was more fundamental than matter. In fact, it is now common knowledge that the atoms of matter themselves consist of still more minute atoms of electricity of different signs—the electron and the proton, and the properties ascribed to the atoms by chemists and physicists can largely be traced to the motions of these subatomic constituents.

## Expanding World-Experience

The principles of dynamics were found to be extremely fruitful in these fields, and as a result of their application, the world of perception expanded enormously, and in two directions (1)—in the direction of the larger world of stars, *the greater Cosmos* and (2)—in the direction of the smaller world of atoms—*the smaller Cosmos.* It is exactly the increase of our experience in these two directions which showed that the principles of dynamics possessed the imperfection, which were suspected, though not definitely detected, by the epistemologists.

It is now old story how the astronomer, provided with the telescope and other physical apparatus which have added substantially to his senses, has been going on with his exploration of heavens, *i.e.*, finding out the distance, size, number, and physical characteristics of the universes which we call stars. The methods used in these explorations are not much different from those used by the surveyor in finding out the height or distance of a distant, inaccessible hill. In course of these explorations millions of worlds resembling our solar system and separated from us by enormous distances have been discovered to be existing in the Great Space. It was from a study of phenomena occurring in these distant worlds that scientists first came to the knowledge that light is propagated with finite velocity, a discovery which is of great importance in modern science, for it allowed them to compare the events occurring in these distant worlds with events occurring in this world,—attempts which ultimately led to the discovery of the Theory of Relativity.

## The Principles of Relativity

The main ideas of Einstein's principle of relativity, have now become very familiar, but it is very difficult to appreciate their full import on our classical method of analysing the world-picture. The basis of classical dynamics are three fundamental concepts, *viz.*, that of mass as a property inherent in every piece of matter; the assumption that space can be measured according to the principles laid down by Euclid; the idea of time as a sort of uniform flux. We have already referred to the objections of metaphysicians against these concepts, but have not discussed the nature of the objections. An analysis of Galileo's ideas shows that it is impossible to assure the divisibility of space without bringing in the divisibility of time. The divisibility of length is easily conceived, but what is meant by divisibility of time? Time is one thing with which no experiment was supposed to be possible till Einstein appeared on the scene. But Galileo endowed time with the attribute of infinite divisibility and thus identified duration with extension. In this way, the first steps were taken in converting the science of mechanics into a section of Geometry, but it led to two logical deductions, *viz.*, to the conclusion that Space and Time are of infinite extent. These ideas fitted into the conceptions of Euclidean Geometry. But many old philosophers, notably Descartes, protested against the assumption of an infinite Universe. According to Descartes the extent of the Universe is to be determined by the amount of matter contained in it, and if there were no matter, there would be no space. What Einstein has done is to demonstrate that experimentation with time is also possible and was, in fact, carried out by Michelson and Morley in their famous "Aether-drift" experiment, though the investigators themselves were ignorant of the meaning of their experiment. He found that time and space can no longer be treated as independent of each other, but they enter into a sort of loose connection, making the world of senses four-dimensional, in which we no longer talk of points,

but must talk of events, *i.e.,* points observed at a definite instant of time. The term "distance" ceases to have any logical meaning. Time ceases to be absolute, and, with that, the physicist's dream of making an objective world-picture, independent of the state and motion of the observer, recedes to background. How, under such circumstances, can motion be treated, or can we find substitutes for the law of gravitation, which involves terms like "mass" and "distance," which have now become illogical, and are to be regarded as mere anachronisms.

But Einstein was not a mere iconoclast, he also showed the way for a new reconstruction. He picks up old time-honoured principles, and generalises them according to the new ideas. The corner-stone in his new theory is that mechanics is part of the Geometry of a four-dimensional space-time manifold possessing metrical properties which he identifies with physical characteristics of matter. One interesting result which follows is that he finds that space, and possibly time also, is not infinite, but the extent of the space is conditioned by the amount of mass contained in it, a result which was vaguely foreseen by metaphysicians like Descartes as already mentioned.

Modern astronomical observations have shown that the more distant Nebulæ are receding from us with enormous speed—in fact, the more distant is the Nebulæ, the greater is the speed. This has given rise to the alluring theory of "Expanding Universe" which now forms an entertaining topic for newspaper science. But the world of perception is much larger, and, besides gravitation, very few of the other properties of matter has so far been accounted for by the special theory.

## The Intra-atomic World

All that I have recounted is now old story, and I now turn to the second group of difficulties caused by the emergence of the *quantum* of action, which was first introduced in physics in the year 1900 by Professor Planck of Berlin. It came no bigger than as a mere speck of cloud in the otherwise clear sky of a self-satisfied physics, and was believed by many distinguished physicists as a mere illusion. But it persisted in staying, and, as every physicist now knows, it has proved to be the "*elan vitale*" of the atomic world. The point which I have in mind may be easily illustrated by subjecting Bohr's picture of the atom to a critical analysis. The H-atom in his picture consists of the proton round which the electron revolves in orbits which we may attempt to calculate with the aid of classical mechanics. But there is one important desideratum. We have no means of finding the value of the angular momentum which should be constant In cases of planetary motion this is obtained from initial conditions, but in the case of the electron it is not possible to subject the atoms of which they form part to direct visual observations. The quantity must, therefore, be guessed. This feat was first accomplished twenty years ago by Niels Bohr of Copenhagen who showed that it must be proportional to Planck's quantum of action because both have the same dimensions; and with some modification the conjecture proved to be highly successful.

F. 4

The account of Bohr's theory of the H-atom has now passed even into elementary text books, and it has formed the basis of subsequent theories of atomic structure which aim at explaining all the physical and chemical properties assigned to the atom. I wish to speak only of certain logical difficulties in this picture. We find that the electron can revolve only in a certain number of orbits, which can be labelled by the successive integral numbers 1, 2, 3 . . . according to the units of angular momentum possessed by the electrons in the different orbits. The question immediately arises : Why are we compelled to limit the orbits to integral numbers? The second point is that the electron, if it is once in a higher, say, the 5th orbit, cannot stay there long but experience tells us that after a period of 10—8 sec. or so it comes back to some lower state, the 4th, 3rd, 2nd, or the 1st. But it cannot be precisely stated as to which of these orbits the electron will jump. Experience tells us that the tendency to jump to any orbit is measurable in terms of a definite transition probability for each jump.

## Is the Principle of Causality to be Given Up?

This last circumstance at once brings our picture into definite conflict with the principle of causality which forms the basis of classical dynamics. This principle tells us that for every observed effect there must be a precisely definable cause, which uniquely determines the effect. For example, why does a planet move in a definite orbit round the sun? The cause is that the planet is subject to the law of universal gravitation discovered by Newton, and was observed at a definite instant to move with a definite velocity at a definite distance. These conditions completely determine the *destiny* of the planet. If it is ever found to deviate from the calculated orbit, it must be due to some unknown cause, *e.g.*, the proximity of a third planet. It will be easily perceived that belief in the principle of causality is the very foundation of Modern Science; for if with ancient philosophers we believed that everything is ordained by a Higher Will, no need for scientific study remains. The achievement of the mediæval philosophers consisted in showing that every observable effect can be traced to a cause which is mathematically definable without the intervention of a Divine Will. The labours of scientists have been directed to find out the succession of cause and effect, and has resulted in the lofty structure which we call modern science. It is true in some sciences, *e.g.*, in meteorology the result has not been encouraging, for has not the unreliability of predictions of weather-prophets passed into a by-word? But no scientist has thereby been led to despair in the truth of the law of causality in this field. He finds, with good reason, that the meteorologist, unfortunately for him, has to deal with very complex questions in which infinite variety of factors are present, and he finds it difficult to distinguish between cause and effect. But it is clear that in the atomic problem Bohr had unwittingly violated this principle by making the electron jump spontaneously from one orbit to another. Classical dynamics does not enable us to say why the electron jumps from the 5th orbit to the 4th or the 3rd.

The idea of transition probability is wholly foreign to it. Bohr endowed the electron with a certain amount of *free will* which enables it to determine its destiny in a limited way but apparently without the intervention of any traceable cause.

The position is thus described by Eddington:—" It is a consequence of the quantum theory that physics is no longer pledged to a scheme of deterministic law. Determinism has dropped out altogether in the latest foundations of theoretical physics, and it is open to doubt whether it will be brought back."

## Failure of Classical Dynamics

I have referred to one difficulty, but in fact there are many others. The exploration of the inside of the atom has yielded much new experience which cannot be fitted within our old framework. Though physicists were conscious of the difficulties they were unwilling to speak out their mind until 1925, when Heisenberg, a young German physicist, boldly proclaimed the unpleasant fact. A new pathway must be found to cope with these new facts of experience. Attempts from many directions are being made since 1925, but I do not think that we have as yet come to anything like a final picture. Divested of technicalities these attempts point to a very fundamental departure. The main task of the physicist is to translate events from the world of perception to the physicists' mental picture. In this process the fundmental unit was the particle of matter which was supposed to occupy a Euclidean space-point at a definite instant of time. But a little thinking will show that the mass-point was merely an abstraction, a creation of the human mind, like the geometer's conception of point or line, and in the whole range of his experience the physicist has never been able to discover an actual mass-point. The old atom was long ago shown by Clausius to have finite extensions, but physics did not stop there. The atom resolved itself into a complex of protons and electrons, which are elementary units of positive and negative electricity. But even these cannot be conceived as points, but appear to have extensions of a baffling nature in space which have long been the subject of debate. The abstract particle of matter is now going to be divested of its elementary nature. According to De Broglie, its place is taken by a narrow wave-train possessing a definite amount of energy, which cannot be located at any geometrical point but is spread throughout its own space. Though this idea has received a certain amount of experimental support I must admit that the picture is rather vague and some workers like Heisenberg and Dirac prefer to work with symbols rather than with a definite model, thus avoiding unseen pitfalls.

## The Uncertainty Theorem

In classical dynamics the state of motion of a particle was defined by its location, position and momenta co-ordinates. But if the elementary unit be a wave-packet it is clear that its location in space-time cannot be defined by a Euclidean point plus a point of time, but a certain amount of latitude is allowed. Heisenberg

argues that this uncertainty is inherent in the nature of things themselves and illustrates it by the following example. Suppose we wish to locate an electron accurately in space ; we can only do so by illuminating it with light and putting it under observation under a highly magnifying microscope. But the image produced of a point by a microscope is a small disc plus a series of circular diffraction rings about it. The position is not uniquely determined, but is subject to an uncertainty equal to the radius of the diffraction ring which is $\lambda/\epsilon$, where $\lambda$ is the wavelength of light used and $\epsilon$ is the angular aperture of the microscope. Hence if we wish to locate the electron sharply, $\lambda$ should be as small as possible, say, a gamma ray. But in trying to locate the position exactly we have brought a further complication on ourselves, for when the light quantum strikes the electron it tends to impart to it a certain amount of energy, a phenomena on which was discovered by A. H. Compton about a decade ago. The changes in momentum is inversely proportional to $\lambda$ and $\epsilon$ and an exact calculation shows that

$$\triangle p \triangle q \sim h$$

where $h$ is Planck's quantum of action

Thus in any physical measurement, the dynamical co-ordinates of position and momentum become uncertain, and mechanics loses the preciseness which was formerly ascribed to it.

In De Broglie's early picture the particle was replaced by a limited wave-packet and he sought to lay down the principles of new dynamics by a point to point comparison between Hamilton's principle of stationary action which in old dynamics was used for describing the formation of particles, and Fermat's principle of least phase, which describe correctly the propagation of light in space. This attempt was further carried on by Schrödinger.

## Schrodinger's Theory of the H-atom

In Schrödinger's picture, the electron becomes something like a stretched membrane which is capable of possessing a number of definite vibrations fixed by boundary conditions. The vibrations of stretched membranes may be familiar to you, at least every student of physics is familiar with them. A circular membrane vibrates in sections marked out by circles concentric with the centre, and in equal sectors into which the circle can be divided. In Schrödinger's picture, the electron which may be supposed to have been replaced by a three dimensional spherical membrane stretching to infinity, is found to vibrate radially and in zones into which the sphere can be divided. These stand for the different classes of stationary vibrations which are visualized by the orbits made familiar by Bohr and Sommerfeld. The transition from one state to another can be compared to the change of the membrane from one state of vibration to another. No will power on the part of the electron is required. We thus save, to a certain extent, the principle of

causality. But the lynx-eyed critic detected holes even in this otherwise alluring picture.

## Logical Incompleteness of Schrodinger's Picture

If a particle of matter can be represented by a wave train, the physicist must demand for a critical examination of the properties of the medium. But the sad experience of Aether, said an emphatic no. A further complication was pointed out by Heisenberg, who showed that the packet cannot hold together for a long time, it must dissolve into nothingness sooner or later. A theory of De Broglie, in which the wave is regarded as something like a ghost whose duty was to pilot the material particle in its career through space-time has also failed, so that the physicists, being tired of drawing pictures which, like modern cinema films, do not last for more than a season, are at the present time taking refuge in symbols. Heisenberg's Matrices, Sixteen Dimensional Geometry, and Weyl's Group Theory, Spinor-analysis, Half vectors and heaven knows what further complications may not be in store. The old-fashioned physicist, who, like an idolater, must have a picture, feels that his days are numbered, and he must give way to the newer generation, imbued with iconoclastic tendencies.

## The Elementary Mass-Particle

Apart from these difficulties which, as you see, are caused by the emergence of the quantum of action, we have the space-time difficulties pointed out by Einstein. For a well-defined system of dynamics we must have some objective substitutes for the ideas of time, space, and mass, and a substitute for the old-fashioned mass-particle. It should not be thought that I have given you an exhaustive description of all the difficulties of which we are till now cognisant. The electron and the proton, which are so far known to be the elementary particles, are much more complex than the picture conveyed by a geometrical point. They are found, besides possessing an elementary charge, also definite magnetic moments. To account for this fact, the physicists suppose that they are "spinning."

## The Mystery Deepens

But this is only a symbolic way of speaking, and Dirac has shown that all the properties associated with spinning can be deduced if we combine the principles of wave-mechanics with Einstein's theory of special relativity. But so enormous is the mass of operations piled up for this purpose that the inner mechanism is entirely concealed from the view; and one who has the patience to read through the paper is left with the impression that a gigantic machinery has been set in motion to crack a nut. And though the nut is apparently cracked, very strange stuff comes out of the interior for which the author was not prepared. For Dirac's theory gives rise to many unfamiliar terms like 'negative mass' and 'free magnetic poles'

which possess strange and weird properties. For example, a pair of negative and positive masses, in spite of the existence of an attractive force between them, will go on chasing each other in space like a pair of ill-humoured ghosts. To some investigators, Einstein's metrical space-time manifold is like a magician's hat out of which every conceivable surprise is possible. For example, Eddington thinks that the radius of the electron is determined by the radius of the Einstein-Universe divided by the square root of the number of protons in the universe. When I read this paper, I had a feeling that we are returning to the world of the ancients, when it was supposed that man's destiny in space-time was determined by the position of planets and stars in the heavens. We have a bewildering mass of speculations rife now, and the unfortunate reader feels like a Columbus cruising in the uncertain waters of the Atlantic. The solid land is yet to come.

### Wanted a Mathematical Messiah

Now I wish to finish. On account of the limitation of the time at my disposal I have not been able to give more than a few snap-shots of the multifarious problems now agitating the mind of the physicist. As you have seen, his world of perception has expanded so enormously (on account of multiplication of workers, and invention of apparatus which have added to his senses) that he is for the moment unable to translate his impressions to his mental picture. The physicist is looking forward to the appearance of a Mathematical Messiah to help him out of his troubles. To the general public, and to those not initiated into the mysteries of this abstruse science, the mathematician is a queer creature, working out phantasies with magic symbols. But occasions have been known when delightful surprises have come from this quarter. Here are a few samples in the words of a critical writer :

"The conic sections, invented in an ¡attempt to solve the problem of doubling the altar of an oracle, ended by becoming the orbits followed by the planets in their courses about the sun. The imaginary magnitudes invented by Cardan and Bombelli describe in some strange way the characteristic features of alternating currents. The absolute differential calculus, which originated as a phantasy of Riemann, became the mathematical vehicle for the theory of Relativity. And the matrices which were a complete abstraction in the days of Cayley and Sylvester appear admirably adapted to the exotic situation exhibited by the quantum theory of the atom." (Tobias Dantzig : *Number, the Language of Science.*)

But at the present time the Messiah is not yet in sight, and the physicist, uncontrolled by any sobering influence, finds himself dazed by his own discoveries and unable to interpret his results. But let us hope, as time goes on, we shall have more and more light regarding the mysterious Universe !

# SPEECH BY THE HON'BLE MR. J. P. SRIVASTAVA

EDUCATION MINISTER OF THE UNITED PROVINCES OF AGRA AND OUDH

AT THE ANNUAL MEETING OF THE ACADEMY OF SCIENCES,
ALLAHABAD, JANUARY 13, 1933.

DR. SAHA, LADIES AND GENTLEMEN,

I feel it to be a great honour to preside over this meeting here, but I feel a great diffidence because I am undertaking a task in which a brilliant lead was taken last year by so distinguished a person as His Excellency Sir Malcolm Hailey. I am very glad, indeed, to note that within a short period the U. P. Academy of Sciences has attained this position. It has established for itself a name not only in this country, but also in Europe and the Western countries. This result is largely due to the personality of the people behind it. You have in your president a very distinguished scientist—(cheers)— whose name is a household word all the world over. He has made various contributions to science which have been appreciated by everybody. Dr. Saha is correct in saying that His Excellency the Governor has taken a keen interest in this Academy. In fact we are only sorry that we have not been able to be of greater benefit to the Academy. I know you want more money, but money has been scarce, and if we have not been able to give to your expectations, this is not due to any lack of appreciation on our part—we would have done more if we could.

## No Last Word

I am not going to enter into the intricacies of Dr. Saha's address this afternoon. He has taken you through a maze of things which has left us all bewildered. There seems to be one thing certain that there is no last word in science, the domain of science seems to be too littered with ideas to be gone into fully, and what is to come next we do not know. The development of scientific research in India is of recent date but I think we have taken a great stride. The award of the Nobel Prize to an Indian scientist is a recognition of the first order and your own achievements here will tell you that you are not lagging behind. If you go through the Bulletin of the Academy you will find that the contributions you have been making to scientific knowledge have been very great indeed. In his speech last year Dr. Saha struck rather a plaintive note and said that science has not received the recognition that it should. It is often said that the average man suffers from lack of ideas

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and ignorance and so he cannot take a lively interest in scientific research, but I think we should not jump to the conclusion that he is not at all interested in science as he seems to acquiesce in the benefits that accrue to him as a result of the labours of the scientists and desires—if only from a selfish point of view—that science should continue to make progress to give him further benefits. Science, to-day, is of the greatest advantage to this country. Considering the needs of India there is before you, the scientists, a very wide field of public service apart from the efforts that you make to add to the sum-total of your scientific knowledge. That the lead must be given by scientists in this matter is, I believe, realised by all thinking people.

## Practical Benefits

We have no doubt that the ordinary man or even the politician of whom you spoke a little deprecatingly—(cheers)—expects only practical benefits from science This attitude may not appeal to the scientists, but still the man-in-the-street and the general public want science to render some service which will be of practical value to them. We, in India, have a great problem before us ; that is, finding jobs for our educated young men. The politician can do something towards this end, but a great deal of help can be given by scientists. You have referred, Mr. President, to the work which it is possible to do for the sugar industry. There are various other lines in which the scientist can render most useful service. We do have a difficult problem, the solution of which rests with the scientists working in cooperation with the politician, if I may say so.

## Industrialisation

Your researches could do a lot to improve the pace at which the country is being industrialised. There are numerous industries which could be helped by scientists and I am very glad to say that your Academy of Sciences is not devoting itself wholly to academic research. You are doubtless aware that with the help of Sir C. V. Raman and as a result of the munificence of the late Rao Saheb Dr. Lakshmi Narayan a large sum has been given to industrial research in the Central Provinces. I hope the United Provinces will not lag behind. Similar efforts have to be made all over the country and I am sure public support and private benefactions will be forthcoming.

The result already achieved by the U. P. Academy of Sciences is itself an invitation for such help and I am quite certain that people will not be found wanting in giving support to the Academy in its work.

## Unemployment

You are doubtless aware that the U. P. Government have been making some efforts to solve the problem of unemployment of the middle classes. We have just appointed a Committee to go into the question of settling young men on land, the

idea being that young men who have had scientific education would be able to increase the production of land and thereby make a living for themselves. There, again, the scientists could be of great value. I believe Dr. Saha put up a proposition last year for the development of industries and agriculture in the country which deserves careful consideration. His suggestion to my mind is a very good idea, but of course it may not appeal to the pure financier. In this work you will want the combined help of the scientist and the politician and last of all the financier. Times are bad and all governments even the Government of the United Provinces are helpless in the matter of funds. Well, Ladies and Gentlemen, I do not think I need keep you much longer. I wish to thank Dr. Saha for the personal reference he has made about me. I have come to this Vizianagram Hall after twenty-five years, but I find the Hall same as it was. I am very glad now that the band of scientists that you have in this University is doing useful work and I wish to assure you that so far as the Government of the United Provinces is concerned it will not be wanting in giving you whatever help it can. I need not add that I wish the Academy every success and prosperity, and I wish to congratulate it on its new President, Dr Bahl.

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# VOTE OF THANKS BY PROF. K. N. BAHL

I am very thankful to the members of the Academy of Sciences for electing me as their President for the year. I am fully conscious of the heavy responsibility imposed upon me, following as I do Dr. Saha, the founder of the Academy. By virtue of his eminent scientific attainments, Dr. Saha has set up a very high standard which it would be difficult for me to approach. But I feel encouraged in my task by the confidence you have reposed in me, and I hope, with your good-will and co-operation, I shall be able to promote the best interests of the Academy during the coming year.

My very first duty as the President of the Academy is a most pleasant one, which is to propose a very hearty vote of thanks to the Hon'ble Minister, Mr. Srivastava, who has taken the trouble of coming over to Allahabad to preside over this function. A very busy person as he undoubtedly is, it is very good of him to have spared the time to attend our annual meeting, this afternoon. Although it is the first time that the Hon'ble Minister has attended a function of the Academy, he has already given proof of his practical sympathy with our aims and objects, as I have no doubt that the annual grants which we get from the Government, are received through his kind help and active support.

I think it is too late in the day to stress the importance of scientific work in the material advancement of our country, and particularly so in the case of our Hon'ble Minister, who has been a man of science himself, and who, as a captain of industry, has made use of the practical applications of science. He realises full well that the money spent on scientific research is a sound investment which is sure to bring a good return.

I shall ask you, ladies and gentlemen, to join with me in according a hearty vote of thanks to the Hon'ble Minister.

# VOTE OF THANKS BY PROF. N. R. DHAR

I have great pleasure in seconding the vote of thanks moved by my friend Dr. Bahl. In our Province we had Journalist Ministers, Lawyer Ministers in charge of education, but we are lucky now to have a Scientist Minister at the head of affairs. We hope that education in general and science in particular, will flourish under his *regime*.

Scientific education is costly no doubt, but it recompenses the community thousandfold by way of improvement in industry and agriculture. We hope that the money spent for the Academy of Sciences will be repaid by the improvement of scientific, industrial, and agricultural education of the Province.

# OBITUARY

## Dr. Winfield Dudgeon

We regret to record the death of Dr. Winfield Dudgeon, Ph. D. on December 26th, 1932 from an attack of influenza in America where he had gone on furlough and was doing research work at the University of Chicago.

He was in charge of the Department of Biology, Ewing Christian College, Allahabad, and was a part-time teacher in the Department of Botany, Allahabad University.

Dr. Dudgeon was born in 1886 and came out to India in 1912 to join the Ewing Christian College while his connection with the University of Allahabad began in 1922. In 1917, he received the Ph D. degree of the University of Chicago, U.S.A.

Dr. Dudgeon was for years a member of the Botanical Society of America, of the Indian Science Congress, and of the Indian Botanical Society. He served as the first president of the last-named organization in 1921. He also served as President of the Botanical Section of the Indian Science Congress in 1922. He was a member of the American Honorary Scientific Society, "Sigma XI," and of the more specialized honorary botanical society, "Phi Kappa Phi." He was for some time chairman of the committee of courses in Biology of the U. P. Board of Intermediate and High School Education.

He was not only an enthusiastic teacher but a keen researcher. His chief papers were : —

1. Morphology of Rumex crispus—1918.
2. A contribution to the Ecology of the Upper Gangetic plain—1920.
3. Succession of Epiphytes in the Quercus Incana Forest at Landour, Mussoorie, Western Himalayas—1923.
4. Ecology of Tehri Garwal—1925.

He also published two very useful books :—

(1) Guide to Intermediate Practical Botany.

(2) Key to Mussoorie Plants

During the last few years he was engaged in research on mango flowers and he was completing this work in America at the time of his death. He was further preparing a Memoir on the " Forest Plants of Central India."

His death deprives the Ewing Christian College and the Allahabad University of one of the ablest of Indian Botanists, an inspiring teacher of great ability and experience and a devoted investigator of great merit. He is greatly lamented by his students and friends to whom he endeared himself by his liberality and sincerity.

# BULLETIN

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## ON AN INFINITE SERIES OF INTEGRALS INVOLVING STURM—LIONVILLE EIGEN FUNCTIONS

### By M. Raziuddin Siddiqi

Department of Mathematics, Osmania University.

### Introduction.

In a previous paper[1] it has been proved by the writer that the series

$$\frac{\sum\limits_{n} n\, |a^{(n)}_{k,\,j}|}{k_1{}^2 k_2{}^2 \ldots k_r{}^2 j_1{}^3 j_2{}^3 \ldots j_s{}^3}, \text{ where}$$

$$a^{(n)}_{k,\,j} = j_1 j_2 \ldots j_s \int_{0}^{\pi} \sin k_1 x \ldots \sin k_r\, x \cos j_1 x \ldots \mathrm{Cos}\, j_s\, x\, \sin n\, x\, dx \text{ is}$$

uniformly convergent for all $k_r$, $j_s$

Now $\sin n\, x$ is just the Eigen function of a particular differential equation, viz. $\dfrac{d^2 y}{dx^2} + \lambda y = o$ for certain boundary values, viz. $y(o) = o$, $y(\pi) = o$, and it is natural to ask, therefore, whether a similar property is possessed by other Eigen-functions.

In another paper[2] the writer has shown that if $\lambda_n$ $(n = 1,\ 2, \ldots)$ are the Eigen-values and $\phi_n\,(x)$ the corresponding Eigen-functions of the Sturm-Lionville Differential Equation

$$\frac{d}{dx}\left(p\frac{dy}{dx}\right) + \lambda y = o$$

with the boundary conditions $y(o)=o$, $y(\pi)=o$, and if we define

$$a_{j,k}^{(n)} = \int_0^\pi \phi_j(x)\phi_k(x)\phi_n(x)dx,$$

then the series $\dfrac{\sum\limits_n |a_{j,k}^{(n)}|}{\lambda_j\,\lambda_k}$ is uniformly convergent.

In the present paper, we prove the more general theorems that the series

$$\frac{\sum\limits_{n=1}^{\infty}\sqrt{\lambda_n}\,|a_{j,k}^{(n)}|}{\lambda_j\,\lambda_k},$$

and

$$\frac{\sum\limits_{n=1}^{\infty}\sqrt{\lambda_n}\,|b_{k,j}^{(n)}|}{\lambda_k\,\lambda_j{}^{\frac{3}{2}}},$$

also converge uniformly for all $j$, $k \geq 1$, where

$$b_{k,j}^{(n)} = \int_0^\pi \phi_k(x)\frac{d\phi_j}{dx}\phi_n(x)\,dx.$$

These Theorems are important in the theory of higher partial differential equations, as has been shown by the writer in a paper communicated to the London Math. Society.

§1.

Let $p(x)$ be an essentially positive function defined in the interval $o \leq x \leq \pi$, and let $p(x)$ as well as $\dfrac{dp}{dx}$ and $\dfrac{d^2p}{dx^2}$ be continuous and uniformly bounded in the whole interval.

Let $\lambda_n$ be the characteristic values and

$$\phi_n(x) \quad (n=1, 2, 3, \ldots )$$

the characteristic functions of the Sturm-Lionville differential equation

(A) 
$$\frac{d}{dx}\left(p\frac{dy}{dx}\right)+\lambda y=o$$

with the boundary conditions

(B) 
$$y(o)=o,\ y(\pi)=o.$$

We assume that the characteristic functions are orthogonal and normalised.

For any pair of $j$, $k$ we define a sequence of functions $a_{j,k}^{(n)}$ by the relation

(1) 
$$a_{j,k}^{(n)} = \int_0^\pi \phi_j(x)\,\psi_k(x)\,\phi_n(x)\,dx.$$

$$(n=1, 2, \ldots )$$

and we shall prove the theorem that the series

(2)
$$\sum_{n=1}^{\infty} \frac{\sqrt{\lambda_n}\, |\, a_{j,\,k}^{(n)}\, |}{\lambda_j \, \lambda_k}$$

is uniformly convergent for all $j$, $k$.

The asymptotic expansions of $\lambda n$, $\phi n\ (x)$ and $\dfrac{d\phi_n}{dx}$ for large $n$ are known to be [3])

$$\lambda_n = n^2 \frac{\pi^2}{l^2} + O\,(1), \quad \sqrt{\lambda_n} = n\,\frac{\pi}{l} + O\left(\frac{1}{n}\right),$$

(3)
$$\phi_n\,(x) = C_n \frac{\sin n\, p_2\,(x)}{\sqrt[4]{p}} + O\left(\frac{1}{n}\right),$$

$$\frac{d\phi_n}{dx} = C_n \frac{n\pi}{l} \frac{\cos n\, p_2\,(x)}{\sqrt[5]{p}} + O\,(1),$$

where

$$l = \int_0^{\pi} \frac{1}{\sqrt{p}}\, dx,$$

(4)
$$p_2\,(x) = \frac{\pi}{l} \int_0^x \frac{1}{\sqrt{p}}\, dx$$

$$\frac{1}{C_n^2} = \int_0^{\pi} \frac{\sin^2 n\, p_2\,(x)}{\sqrt{p}}\, dx.$$

Now, since $p\,(x)$ is essentially positive and $\sin n\, p_2\,(x)$ does not vanish identically in $0 \le x \ge \pi$, we deduce that $\dfrac{1}{C_n}$ is greater than a + ve number c for all $n$, and therefore $C_n$ is bounded. Consequently, the functions $\phi_n\,(x)$ and $\dfrac{1}{n}\dfrac{d\phi n}{dx}$ are also bounded for all $n$.

Now, we have

$$a_{j,\,k}^{(n)} = \int_0^{\pi} \phi_j\ \phi_k\ \phi_n\ dx;$$

integrating by parts and considering that $\phi_n$ satisfies the equation (A) and the condition (B), we get:

$$\underset{j,\,k}{a(n)} = -\frac{1}{\lambda_n} \int_0^\pi \phi_j(x)\,\phi_k(x)\,\frac{d}{dx}\left\{ p\,\frac{d\phi_n}{dx} \right\} dx,$$

$$= -\frac{1}{\lambda_n} \int_0^\pi \phi_n(x)\,\frac{d}{dx}\left\{ p\,\frac{d}{dx}(\phi_j\,\phi_k) \right\} dx,$$

$$= -\frac{1}{\lambda_n} \int_0^\pi \phi_n(x) \left[ \frac{d}{dx}\left( p\,\frac{d\phi_j}{dx} \right)\phi_k(x) + \frac{d}{dx}\left( p\,\frac{d\phi_k}{dx} \right)\phi_j \right.$$

$$\left. + 2\,p\,\frac{d\phi_j}{dx}\,\frac{d\phi_k}{dx} \right] dx,$$

$$= -\frac{1}{\lambda_n} \int_0^\pi \phi_n(x) \left\{ -(\lambda_j + \lambda_k)\,\phi_j(x)\,\phi_j(x)\,\phi_k(x) \right.$$

$$\left. + 2\,p\,\frac{d\phi_j}{dx}\,\frac{d\phi_k}{dx} \right\} dx.$$

Since $\lambda_j$, $\lambda_k$ are $> 1$ for all $j$, $k$, therefore we have

(5)
$$\frac{\left| a_{j,\,k}^{(n)} \right|}{\lambda_j\,\lambda_k} < \frac{2}{\lambda_n}\left\{ \left| a_{j,\,k}^{(n)} \right| + \left| d_{j,\,k}^{(n)} \right| \right\},$$

where

(6)
$$d_{j,\,k}^{(n)} = \int_0^\pi p(x)\,\frac{1}{\lambda_j}\,\frac{d\phi_j}{dx}\,\frac{1}{\lambda_k}\,\frac{d\phi_k}{dx}\,\phi_n\,dx$$

Therefore,

(7)
$$\left( \sum_n \sqrt{\lambda_n}\,\frac{\left| a_{j,\,k}^{(n)} \right|}{\lambda_j\,\lambda_k} \right)^2 < \left( \sum_n \frac{2}{\sqrt{\lambda_n}}\left\{ \left| a_{j,\,k}^{(n)} \right| + \left| d_{j,\,k}^{(n)} \right| \right\} \right)^2$$

$$< \sum_n \frac{4}{\lambda_n}\,\sum_n \left\{ \left| a_{j,\,k}^{(n)} \right| + \left| d_{j,\,k}^{(n)} \right| \right\}^2$$

using the inequality of Schwarz. If we use further the inequality $2ab \geqq a^2 + b^2$, then we get

(8)
$$\left( \sum_n \sqrt{\lambda_n}\,\frac{\left| a_{j,\,k}^{(n)} \right|}{\lambda_j\,\lambda_k} \right) < \sum_n \frac{8}{\lambda_n}\,\sum_n \left\{ \left| a_{j,\,k}^{(n)} \right|^2 + \left| d_{j,\,k}^{(n)} \right|^2 \right\}$$

But we have

$$\phi_j(x)\,\phi_k(x)\,\phi_n(x) = \left\{ C_j\,\frac{\sin j\,p_2}{\sqrt[4]{p}} + O\left(\frac{1}{j}\right)\right\}\left\{ C_x\,\frac{\sin x\,p_2}{\sqrt[4]{p}} + O\left(\frac{1}{k}\right)\right\}$$

$$+ \left\{ C_n\,\frac{\sin n\,p_2}{\sqrt[4]{p}} + O\left(\frac{1}{n}\right)\right\}$$

and since all the $C_n$ are bounded uniformly, we can write

$$(9)\quad \int_0^{\pi}\phi_j(x)\,\phi_k(x)\,\phi\,(x)\,dx < a\int_0^{\pi}\frac{\sin j\,p_2\,\sin k\,p_2\,\sin n\,p_2}{p^{\frac{3}{4}}}\,dx$$

$$+ \beta\,\frac{1}{j\,k\,n},$$

where $a$ and $\beta$ are constants properly chosen.

$$\text{Now } p_2(x) = \frac{\pi}{l}\int_0^{x}\frac{1}{\sqrt{p}}\,dx,$$

therefore

$$\frac{d\,p_2}{d\,x} = \frac{\pi}{l}\,\frac{1}{\sqrt{p}}\,,\ p_2(0)=0,\ p_2(\pi)=\pi$$

So that

$$(10)\quad \int_0^{\pi}\phi_j(x)\,\phi_k(x)\,\phi_n(x)\,dx < \frac{a\,l}{\pi}\int_0^{\pi}\frac{\sin j\,p_2\,\sin k\,p_2\,\sin n\,p_2}{\sqrt{p}}\,d\,p_2$$

$$+ \beta\,\frac{1}{j\,k\,n}\,.$$

Therefore

$$(11)\quad \sum_n (a_{j,k}^{(n)})^2 < \frac{a^2\,l^2}{\pi^2}\sum_n\left(\int_0^{\pi}\sin j\,p_2\,\sin k p_2\,\sin n p_2\,.\,\frac{1}{\sqrt{p}}\,dp_2\right)^2$$

$$+ \frac{2\,a\,l\,p}{\pi\,j\,k}\sum_n\frac{1}{n}\int_0^{\pi}\sin j\,p_2\,\sin k p_2\,\sin n\,p_2\,\frac{1}{\sqrt{p}}\,dp_2$$

$$+ \frac{\beta^2}{j^2\,k^2}\,.\,\sum_n\frac{1}{n^2}\,.$$

The series

$$(12)\quad \sum_n\left(\int_0^{\pi}\sin \cdot j\,p_2\,\sin k p_2\,\sin n p_2\,.\,\frac{1}{\sqrt{p}}\,.\,dp_2\right)^2$$

is uniformly convergent for all $j$, $k$[4].   Moreover,

$$\sum_n \frac{1}{k\,j\,n} \int_0^\pi \sin jp_2 \; \sin kp_2 \; \sin \; np_2 . \; \frac{1}{\sqrt{p}} \; dp_2$$

$$= \sum_n \frac{1}{k\,j\,n^2} \int_0^\pi \cos \; np_2 \; \frac{d}{dp_2} \left\{ \frac{1}{\sqrt{p}} \; \sin kp_2 \; \sin jp_2 \right\} \; dp_2$$

$$= \sum_n \frac{1}{n^2} \int_0^\pi \cos \; n p_2 \; \frac{d}{dp_2} \left\{ \frac{1}{\sqrt{p}} \; \frac{\sin kp_2}{k} \; \frac{\sin j p_2}{j} \right\} \; dp_2 .$$

For all values of $jk$, the integral on the right is uniformly bounded, and therefore the series

$$(13) \quad \sum_n \frac{1}{k\,j\,n} \int_0^\pi \frac{1}{\sqrt{p}} \; \sin \; jp_2 \; \sin kp_2 \; \sin np_2 \; dx$$

is uniformly convergent.

Also for all $j$, $k$

$$\frac{1}{j^2 k^2} \sum_n \frac{1}{n^2} \leqq \frac{\pi^2}{6} .$$

From (13), We see therefore that the series

$$(14) \qquad \sum_n \left( a_{j,\,k}^{(n)} \right)^2$$

is uniformly convergent for all $j$, $k$.

Now, $\quad p(x) \phi_n(x) \frac{1}{\lambda_j} \frac{d\phi_j}{dx} \frac{1}{\lambda_k} \frac{d\phi_k}{dx} = \left\{ C_n \; p^{\frac{3}{4}} \sin np_2 + O\left(\frac{1}{n}\right) \right\}$

$$+ \left\{ \frac{C_j \; l}{\pi \; j} \; p^{-\frac{1}{5}} \cos j \, p_2 + O\left(\frac{1}{j^2}\right) \right\} \; \left\{ \frac{C_k \; l}{\pi \; k} \; p^{-\frac{1}{5}} \cos k \, p_2 + O\left(\frac{1}{k^2}\right) \right\}$$

So that

$$(15) \quad 1 d_{j,\,k}^{(n)} 1 \; < \; \frac{\gamma}{kj} \int_0^\pi p^{\frac{7}{20}} \cos j \, p_2 \; \cos kp_2 \; \sin \; n \; p_2 + \delta \frac{1}{k^2 j^2 n} 1$$

where $\gamma$ and $\delta$ are two constants properly chosen.

Exactly as in the case of the series $\sum\limits_{n}\left(a_{j,\,k}^{(n)}\right)^{2}$, it can be proved that also the series

(16) $$\sum\limits_{n}\left(d_{j,\,k}^{(n)}\right)^{2}$$

is uniformly convergent for all $j,\,k$.

Also, since $\sum\limits_{n}\dfrac{1}{\lambda_{n}}$ is evidently convergent, we see from (8) on account of (14) and (16) that the series

(17) $$\sum\limits_{n=1}^{\infty}\sqrt{\lambda_{n}}\,\frac{|\,a_{j,\,k}^{(n)}\,|}{\lambda_{j}\,\lambda_{k}}$$

converges uniformly for all $j,\,k$.

§2.

In this paragraph, we shall prove that on defining the sequence of functions $b_{k,\,j}^{(n)}$ more generally by the Integral.

(18) $$b_{k,\,j}^{(n)}=\int_{0}^{\pi}\phi_{k}(x)\frac{d\phi_{j}}{dx}\phi_{n}(x)\,dx$$

a similar theorem holds, viz. that the series

(19) $$\sum\limits_{n=1}^{\infty}\frac{\sqrt{\lambda_{n}}\,|\,b_{k\,j}^{(n)}\,|}{\lambda_{k}\,\lambda_{j}^{\frac{3}{2}}}.$$

converges uniformly for all $k,\,j$.

Since $\phi_{n}(x)$ satisfies the differential equation (A) we can write (18) in the form

(20) $$b_{kj}^{(n)}=-\frac{1}{\lambda_{n}}\int_{0}^{\pi}\phi_{k}\,\phi'_{j}\left(p\phi'_{n}\right)'dx,$$

where dashes are used to denote derivatives. Integrating by parts and remembering that $\phi_{n}(x)$ satisfies the boundary conditions (B), we get

$$b_{k,\,j}^{(n)}=\frac{1}{\lambda_{n}}\int_{0}^{\pi}\phi'_{n}\,p\left(\phi_{k}\,\phi'_{j}\right)'dx$$

$$=\frac{1}{\lambda_{n}}\int_{0}^{\pi}\phi'\left\{p\phi'_{k}\,\phi'_{j}-\lambda_{j}\,\phi_{k}\,\phi_{j}-p'\phi_{k}\,\phi_{j}\right\}dx.$$

Integrating again by parts, we have,

$$b_{k,j}^{(n)} = -\frac{1}{\lambda_n} \int_0^\pi \phi_n \left\{ \left( p\, \phi_k{}' \phi_j{}' \right)' - \lambda_j \left( \phi_n \phi \right)' - \left( p' \phi_k \phi_j \right)' \right\} dx$$

$$= -\frac{1}{\lambda_n} \int_0^\pi \phi_n \left\{ p' \phi_k' \phi_j' + p \phi_k'' \phi_j' + p \phi_k' \phi_j'' - \lambda_j' \phi_k' \phi_j \right.$$
$$\left. - \lambda_j \phi_k \phi_j' - p'' \phi_k \phi_j' - p' \phi_k' \phi_j' - p' \phi_k \phi_j'' \right\} dx,$$

$$= -\frac{1}{\lambda_n} \int_0^\pi \phi_n \left\{ \phi_j' \left( -\lambda_k \phi_k - p' \phi_k' \right) + \phi_k' \left( -\lambda_j \phi_j - p' \phi_j' \right) \right.$$
$$\left. - \lambda_j \phi_k' \phi_j - \left( \lambda_j + p'' \right) \phi_k \phi_j' + \frac{p'}{p} \phi_k \left( \lambda_j \phi_j + p' \phi_j' \right) \right\} dx,$$

$$(21) \quad = -\frac{1}{\lambda_n} \int_0^\pi \phi_n \left\{ \phi_k \phi_j \lambda_j \frac{p'}{p} + \phi_k \phi_j' \left( -\lambda_k - \lambda_j - p'' + \frac{p'^2}{p} \right) \right.$$

$$\left. - 2 \lambda_j \phi_k' \phi_j - 2 p' \phi_k' \phi_j' \right\} dx.$$

Now we see that the integrand on the right contains a term $\lambda_j \phi_n \phi_k \phi_j'$, and since in the asymptotic expansion of $\phi_j'$ a factor $j \frac{\pi}{l}$ also comes, it will be obviously not sufficient to divide this term by $\lambda_k \lambda_j$ if we want the quotient to be bounded for all $j$. On the other hand, a division by $\lambda_k \lambda_j^{\frac{3}{2}}$ is quite sufficient for this purpose. Thus we have

$$(22) \quad \frac{|b_{k,j}^{(n)}|}{\lambda_k \lambda_j^{\frac{3}{2}}} < \frac{1}{\lambda_n} \left\{ |e_{k,j}^{(n)}| + |f_{k,j}^{(n)}| + 2|g_{kj}^{(n)}| + 2|p_{kj}^{(n)}| \right\}$$

where

$$e_{k,j}^{(n)} = \int_0^\pi \frac{p'}{p} \phi_k \phi_j \phi_n \, dx$$

$$(23) \qquad f^{(n)}_{k,j} = \int_0^\pi \left( 2 + p'' + \frac{p'^2}{p} \right) \psi_k \frac{\phi'_j}{\sqrt{\lambda_j}} \phi_n \, dx,$$

$$g^{(n)}_{k,j} = \int_0^\pi \frac{\phi'_k}{\lambda_k} \phi_j \, \phi_n \, dx,$$

$$h^{(n)}_{k,j} = \int_0^\pi p' \frac{\phi'_k}{\lambda_k} \frac{\phi'_j}{\lambda_j} \, \phi_n \, dx.$$

Now, it is not difficult to prove exactly as for the series $\sum_n \left( a^{(n)}_{j\,k} \right)^2$ and $\sum_n \left( d^{(n)}_{j,k} \right)^2$ in the first paragraph, that all the series

$$(24) \qquad \sum_n \left( e^{(n)}_{k,j} \right)^2, \quad \sum_n \left( f^{(n)}_{k,j} \right)^2$$

$$\sum_n \left( g^{(n)}_{k,j} \right)^2, \quad \sum_n \left( h^{(n)}_{k,j} \right)^2$$

are uniformly convergent for all $k, j$.

From (22) we get on account of Schwarz's inequality

$$\left( \sum_n \frac{\sqrt{\lambda_n} | b^{(n)}_{k,j} |}{\lambda_k \lambda_j^{\frac{3}{2}}} \right)^2 < \sum_n \frac{1}{\lambda_n} \sum_n \left\{ | e^{(n)}_{k,j} |^2 + | f^{(n)}_{k,j} | + 2 | g^{(n)}_{h,j} | + 2 | h^{(n)}_{k,j} | \right\}^2$$

$$(25) \qquad < \sum_n \frac{1}{\lambda_n} \sum_n \left\{ 6 | e^{(n)}_{k,j} |^2 + 6 | f^{(n)}_{k,j} |^2 + 12 | g^{(n)}_{k,j} |^2 + 12 | h^{(n)}_{k,j} |^2 \right\}$$

using the inequality $2\,e\,f \leq e^2 + f^2$, etc.

From (24) and (25) we see therefore that the series

$$(26) \qquad \sum_n \frac{\sqrt{\lambda_n} | b^{(n)}_{k,j} |}{\lambda_k \lambda_j^{\frac{3}{2}}}$$

converges uniformly for all $k, j$, which proves our theorem.

Finally, we remark that there should be no considerable difficulty in proving the following theorem along similar lines.

If

$$(27) \qquad b^{(n)}_{\substack{k_1, k_2, \ldots k_r \\ j_1, j_2, \ldots, j_s}} = \int_0^\pi \phi_n^{(x)} \phi_{k_1} \phi_{k_2} \ldots \phi_{k_r} \phi'_{j_1} \phi'_{j_2} \ldots \phi'_{j_s} \, dx$$

$$(n = 1, 2, \ldots )$$

then the series

$$(28) \qquad \sum_n \frac{\sqrt{\lambda_n} \left| b_{\substack{k_1, \ldots, kr \\ j_1, \ldots, j_s}}^{(n)} \right|}{\lambda_{k_1}\lambda_{k_2} \ldots \lambda_{k_r} \, \lambda_{j_1}^{\frac{3}{2}} \lambda_{j_2}^{\frac{3}{2}} \ldots \lambda_{j_s}^{\frac{3}{2}}}$$

is uniformly convergent for all $k_r$ and $j_s$.

### References.

[1] M. R. Siddiqi, "Zur Theorie der nicht-linearen partiellen Differential-gleichungen vom parabolischen Typus." *Math. Zeitschrift.* 35, 475 (11), 1931.

[2] M. R. Siddiqi, On an infinite system of non-linear integral equations. *Bull. Cal. Math. Soc.*, 24, pp. 47–51, 1932.

[3] Courant—Hilbert: *Methoden der mathematische Physik 1*, 2nd Ed (1931), pp. 290-291.

[4] M. R. Siddiqi, "Zur Theorie der nicht-linearen partiellen Differential-gleichungen vom parabolischen Typus." *Math. Zeitschrift*, 35, 476 (16), 1931.

# A CLASS OF DIRICHLET'S SERIES POSSESSING ESSENTIAL CHARACTERISTICS OF A TAYLOR'S SERIES

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1. In case of a Taylor's series its circle of convergence is also its circle of absolute convergence, and contains at least one singular point of the function represented by the series. As is well-known, no such simple relation holds in the case of general Dirichlet's series. Indeed a Dirichlet's series convergent in a portion of the plane may be absolutely convergent in a smaller region, and may represent a function all over the plane or in a wider region of it. For example, in the case of the series $\sum_{1}^{\infty} (-1)^{n-1} n^{-s}$, $\sigma_0 = 0$, $\bar{\sigma} = 1$, and the function represented by the series is an integral function of $s$. There is, however, one important class of Dirichlet's series, namely, the series all of whose coefficients are positive, for which the line of convergence is also the line of absolute convergence, and contains at least one singularity of the function represented by the series.[1] My main object in this paper is to point out the existence of another class of Dirichlet's series for which the lines of convergence and absolute convergence coincide and necessarily contain at least one singularity of the function represented by the series. The result obtained in this direction is embodied in the following theorem.

2. THEOREM I.—*If*

(2.1) $\lambda(z)$ *be a branch of an analytic function of* $z$ ($= x + iy = \beta + \rho e^{i\phi}$, $p - 1 < \beta < p$) *in the angle* $|\phi| \leq \alpha$, $\alpha > 0$, *and* $\lambda(z) = o$ ($\rho$) *uniformly in this angle as* $\rho \to \infty$ *;*

(2.2) $\lambda(x)$ *be an* $L-$ *function*[2] *such that it is positive for* $x \geq p$ *and steadily tends to infinity with* $x$ *;*

(2.3) $\lambda'(z) = 0$ (1) *as* $\rho \to \infty$ *uniformly in the angle* $|\phi| \leq \alpha$ *;*

(2.4) $f(\xi)$ *be an analytic function of* $\xi = re^{i\theta}$ *in the angle* $|\theta| \leq \alpha$, $\alpha_1 > 0$, *and satisfy the relation* $f(\xi) = 0$ ($e^{Mr}$), *throughout this angle ;*

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(2.5) $f\{\lambda(z)\}$ *be an analytic function of $z$ in the angle* $|\phi| \leq a$, *and* $|\{\lambda'(z) f\{\lambda(z)\} e^{-k\lambda(z)}(z-\beta)\}| \to 0$ *as* $\rho \to \infty$ *uniformly on the arc* $|z-\beta| = \rho$, $|\phi| \leq a$ *for some positive values of* $k$; *then, if*

$$(2.6) \qquad \lambda(\theta) \equiv \overline{\lim_{r \to \infty}} \frac{\log|f(re^{i\theta})|}{r} \qquad (|\theta| \leq a_1)$$

*be finite, the series*

$$(2.7) \quad H(s) = \sum_{p}^{\infty} \lambda'(n) f\{\lambda(n)\} e^{-s\lambda(n)}, \qquad (s = \sigma + it)$$

*has its abscissae of convergence and absolute convergence each equal to* $\lambda(0)$, *and the line* $\sigma = \lambda(0)$ *contains at least one singularity of* $H(s)$. *Further, $H(s)$ is an analytic function of $s$ in the region lying exterior to the convex curve $\Sigma$ which is the envelope of the lines*

$$(2.8) \qquad \sigma \cos\theta - t \sin\theta = \lambda(\theta), \qquad (|\theta| \leq a_1),$$

*each of which contains at least one singularity of* $H(s)$.

*If $\lambda(\theta) = -\infty$ for any value of $\theta$, the series (2.7) is absolutely convergent over the whole plane, and the function $H(s)$ is an integral function of $s$.*

First of all we shall shew that the series (2.7) is absolutely convergent if $\sigma \geq \lambda(0) + \delta > \lambda(0)$ for every positive $\delta$ howsoever small.

Corresponding to an arbitrarily small positive number $\epsilon$, we can choose a positive integer $n_0$ such that the modulus of the $n$th term of series (2.7) is less than

$$\left\{ |\lambda'(n)| e^{(\lambda(0)+\epsilon-\sigma)\lambda(n)} \right\} \text{ for } n \geq n_0(\epsilon).$$

Now since $\lambda'(x)$ is itself an L-function[3] tending steadily, by virtue of (2.3), to a definite quantity as $x \to \infty$, $|\lambda'(x)| e^{(\lambda(0)+\epsilon-\sigma)\lambda(x)}$ is a positive monotonic function which tends to zero as $x \to \infty$, if $\sigma \geq \lambda(0) + \epsilon + \epsilon' > \lambda(0)$. Hence the series whose $n$th term is $\{ |\lambda'(n)| e^{(\lambda(0)+\epsilon-\sigma)\lambda(n)} \}$ will converge if the integral $\pm \int^{\infty} \lambda'(x) e^{(\lambda(0)+\epsilon-\sigma)\lambda(x)} dx$ converges[4]. That this integral converges for $\sigma \geq \lambda(0) + \epsilon + \epsilon' > \lambda(0)$ is seen by putting $\lambda(x) = y$, and so the series (2.7) is absolutely and uniformly convergent in the half-plane $\sigma \geq \lambda(0) + \delta > \lambda(0)$ for every positive $\delta$, and represents there an analytic function of $s$.

Now if we can only prove that the line $\sigma = \lambda(0)$ contains at least one singularity of $H(s)$, we will have proved that $\overline{\sigma} = \sigma_0 = \lambda(0)$.

Putting $F(z) = \lambda'(z) f\{\lambda(z)\} e^{-s\lambda(z)}$, and applying Cauchy's contour integration theorem, we have

$$\sum_{p}^{n} F(\nu) = \int_{C} \frac{F(z)\,dz}{e^{2\pi i z} - 1} \quad ,$$

where C is the contour formed by the lines $_\beta$R and $_\beta$P given respectively by $\phi = \pm \alpha$, and the arc P Q R $|z - \beta| = n + \tfrac{1}{2} - \beta$, Q being on the $x$-axis. That is,

$$(2.9) \qquad \sum_{p}^{n} F(\nu) = \int_{\beta P} \frac{F(z)\,dz}{e^{2\pi i z} - 1} + \int_{PQ} \frac{F(z)\,dz}{e^{2\pi i z} - 1} + \int_{\beta Q} F(z)\,dz$$

$$+ \int_{\beta R} \frac{F(z)\,dz}{e^{-2\pi i z} - 1} - \int_{QR} \frac{F(z)\,dz}{e^{-2\pi i z} - 1} .$$

Now suppose, in the first instance, that $s$ is real, positive and sufficiently large, and $\rho \longrightarrow \infty$. Then, by virtue of (2.5), the integrals over PQ and QR $\longrightarrow 0$, since $\left|\dfrac{1}{e^{-2\pi i z} - 1}\right|$ and $\left|\dfrac{1}{e^{2\pi i z} - 1}\right|$ are bounded on their respective paths of integration.

It follows, therefore, that, if $s$ is real, positive and sufficiently large,

$$(2.10) \quad H(s) = \int_{\beta}^{\infty} F(x)\,dx + \int_{\beta}^{\infty(a)} \frac{F(z)\,dz}{e^{-2\pi i z} - 1} + \int_{\beta}^{\infty(-a)} \frac{F(z)\,dz}{e^{2\pi i z} - 1}$$

$$= I_1 + I_2 + I_3, \text{ say.}$$

Now we shall show that each of the integrals $I_2$ and $I_3$ represents an integral function of $s$.

To show that $I_2$ represents an integral function of $s$, it is sufficient to show that the integral

$$(2.11) \qquad \int_{\beta}^{\infty} \left| \frac{F(\beta + \rho e^{i\alpha})\, e^{i\alpha}}{e^{-2\pi i(\beta + \rho \cos \alpha + i\rho \sin \alpha)} - 1} \right| d\rho$$

is uniformly convergent throughout any finite domain of the values of $s$.

Now $\qquad \left| \dfrac{e^{-2\pi \rho \sin \alpha}}{e^{-2\pi i(\beta + \rho \cos \alpha)} - e^{-2\pi \rho \sin \alpha}} \right| < K_1 \, e^{-2\pi \rho \sin \alpha}$

on the path of integration.

Also $| F(\beta+\rho e^{ia}) | < K_2\, e^{(M + | s |) | \lambda(z) |} < K_2 e^{(M+ | s |)\epsilon \rho}$ , by virtue of hypothe.cs (2.1), (2.3), (2.4), where $\epsilon$ is an arbitrarily small positive number and $\rho$ is sufficiently large.

Hence the integral (2.11) converges like

$$\int^{\infty} e^{- \rho\, (2\pi \sin\, a - (M + | s |)\epsilon)}\, d\rho$$

which is uniformly convergent for all bounded values of $s$, $\epsilon$ being arbitrarily small.

Similarly we can prove that $I_3$ represents an integral function of $s$.

As regards the integral $I_1$, it is equal to

$$\int_{\beta}^{\infty} \lambda'(x)\, f\{\lambda(x)\} e^{- s\lambda(x)}\, dx = \int_{0}^{\infty} f(\xi) e^{-s \xi}\, d\xi + \text{an integral function of } s.$$

So that

(2.12)                    $H(s) - J(s) = G(s),$

where $G(s)$ is an integral function of $s$, and $J(s)$ is an analytic function of $s$ defined initially by the integral $\int_{0}^{\infty} f(z) e^{-sz}\, dz$.

The equation (2.12) has been obtained on the assumption that $s$ is real, positive and sufficiently large. But as the right-hand side represents an integral function of $s$ the equation persists for all values of $s$. That is, *the finite singularities of $H(s)$ are identical with those of $J(s)$.*

Now by virtue of a result[5] established by me and Mr. Jain recently, $J(s)$ is an analytic function of $s$ in the region lying exterior to a convex curve $\Sigma$ which is the envelope of the lines (2.8) each of which contains at least one singularity of $J(s)$. The same is, therefore, true of $H(s)$, and in particular

$$\overline{\sigma = \sigma_0 = \lambda(0)} = \overline{\lim_{r \to \infty}} \frac{log\, |f(r)|}{r},$$ and the line of convergence contains at least

one singularity of $H(s)$.

If $\lambda(\theta)$ is $-\infty$ for any value of $\theta$, $J(s)$ is an integral function of $s$, and so is $H(s)$.

This completes the proof of our theorem.

### REMARKS

3. Theorem I enables us to study the singularities of a class of Dirichlet's series in terms of those of the Laplace-Abel integral. Now we propose to make a few observations on this theorem.

(*a*) The function $\lambda(z)$ contemplated in the theorem may be any one of a class of functions such as $\dfrac{z}{\log z}$, $\dfrac{z}{\log \log z}$, $z^a$ $(0 < a < 1)$, $\sqrt{z} \log z$, $(\log z)^\beta$, $(\log \log z)^k$, etc. It will be noticed that the hypotheses (2.1), (2.2), (2.3) and (2.5) are all true for such a $\lambda(z)$. If $\lambda(z) = z$, we have the case of a Taylor's series in $e^{-s}$. If $\dfrac{\lambda(n)}{n} \to \infty$ as $n \to \infty$, the line of convergence of a Dirichlet's series is, in general, a singular line.

(*b*) In the coefficient of the $n$th term $\lambda'(n)$ is an essential factor for the truth of the theorem. Suppose $\lambda(z) = \log \log z$, and $f(z) = 1$. Then the theorem fails for the series $\Sigma f\{\lambda(n)\} e^{-s\lambda(n)}$, but holds for $\Sigma \lambda'(n) f\{\lambda(n)\} e^{-s\lambda(n)}$.

(*c*) If $f(z)$ is an integral function of $s$ of exponential type, then $H(s)$ is an analytic function of $s$ outside a closed convex curve $\Sigma$. In particular if $f(z) = \sum\limits_0^\infty \dfrac{c_\nu z^\nu}{\nu!}$ and the series $\sum\limits_0^\infty c_\nu z^\nu$ has the circle of its convergence $|z| = \dfrac{1}{k}$ as a singular line, then the circle $|s| = k$ is a singular line for the function $H(s)$, since $H(s) = G(s) + \sum\limits_0^\infty \dfrac{c_\nu}{s^{\nu+1}}$.

Suppose $H(s) = \sum\limits^\infty \dfrac{\sin\{\pi \log \log n\}}{n \log n} e^{-s \log \log n}$. Then $H(s)$ has singular points at $s = \pm \pi i$, and with the possible exception of the points lying on the line joining these two singular points $H(s)$ is analytic everywhere else in the plane.

(*d*) If $f(z)$ is analytic in the half-plane $R(z) \geqq 0$, and

$$\lambda(\theta) = \theta \sin \theta + \cos \theta \log \cos \theta, \qquad \left(|\theta| \leqq \frac{\pi}{2}\right),$$

then the curve $\Sigma$ is given by $\sigma = \log \cos t$, $\qquad \left(|t| \leqq \dfrac{\pi}{2}\right)$,

and is a singular line for the function $H(s)$.

4. Appealing to another result of the paper already referred to, we can deduce the following theorem :—

THEOREM II. *If in theorem I, $a_1 > \dfrac{\pi}{2}$, and $f(z)$ is such that $f[\lambda(n)] = 0$ for $n = p, p+1, p+2, \ldots$ then $f(z) \equiv 0$.*

For H $(s)$ is now identically zero, and so J $(s)$ must be an integral function of $s$. But, since $a_1 > \dfrac{\pi}{2}$, J $(s)$ is identically zero, and so $f(z) \equiv 0$.

### *References*

[1]  Hardy : *The General Theory of Dirichlet's Series*, Theorem 10.

[2]  Hardy : *Orders of Infinity*, p. 17.

[3]  Hardy : *Orders of Infinity*, p. 34.

[4]  Whittaker and Watson : *Modern Analysis*, Third Edition, p. 71.

[5]  Srivastava and Jain: *Bul. Acad., Sci. U. P.* 2, 60, 1932.

[6]  The same reference as 5, p. 63.

# ON THE ABSORPTION SPECTRA OF PbO AND PbS

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The object of the present experiments is to extend Frank's work on the absorption spectra of saturated alkali halides to a new group of saturated compounds, *viz.*, the oxides and sulphides of di-valent and poly-valent atoms. Very little work has been reported on the absorption spectra of compounds of this type. Experiments on $SO_3$ by A. K. Dutta,[1] on $N_2O_5$, $MoO_3$. and $TeO_3$, by A. K. Dutta, and P. K Sen Gupta,[2] and CdO and ZnO by P. K. Sen Gupta[3] have already been reported. In the present paper experiments on the absorption spectra of PbO and PbS are reported.

## EXPERIMENTAL

Owing to the high melting points of these substances, *viz.*, about 875°C. for PbO and 1100°C for PbS the vacuum graphite furnace of this laboratory was used for heating these substances. At first the salts were put on a silica tube; but on heating it was found that lead glass was easily formed. So the salts were put on asbestos pieces rolled into tubular form which was then inserted in the graphite tube. Asbestos was found not to give any appreciable vapour pressure at the temperatures required. In order to prevent the dissociation of PbO the furnace was evacuated and oxygen at a pressure of 50 cm. was filled in. In the case of PbS the spectra were taken first with the furnace completely evacuated and then with nitrogen at a pressure of 50 cm. This was necessary to prevent the oxidation of sulphur evolved by the dissociation of PbS.

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F. 3

The source of continuous light was a hydrogen tube run by a 2 KW Transformer. Photographs were taken by an $E_3$ quartz spectrograph; the time of exposure being from 2—5 minutes. Copper arc was used for comparison.

## RESULTS

PbO [yellow]

At lower temperatures the 2833A line of lead was prominent indicating that there was a partial decomposition of the oxide. As the temperature was further increased this line broadened out and at about 950°C merged into continuous absorption. This begins with a few bands at 3000 A.U. There is a retransmission followed by a second cut at 2240 A.U.

PbS

The absorption spectra shows a continuous absorption also beginning with a few bands at 3500 A.U. A retransmission in this case also follows with a second cut at 2450 A.U.

## CALCULATION

The photo-chemical reaction may be represented by the following equation; since continuous absorption according to Frak-Condon principle indicates the breaking up of the molecule into constituent atoms, $PbX + h\nu_1 = Pb + X$: where X stands for O or S atom. The dissociation may, however, also occur as

$$PbX + h\nu_2 = Pb + X^{(excited)}$$
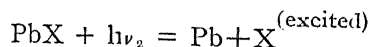
where $h\nu_2 - h\nu_1$ is the excitation energy of X.

From Born cycle we get

$$R = h\nu = Q + \tfrac{1}{2} Dx_2 + L_{Pb} - L_{PbX} + L_X . \quad \dots (1)$$

Where $Q$  =  the latent heat of formation of [Pb X] from [Pb] $+ \tfrac{1}{2} [X_2]$

$\quad D_{X_2}$  =  the heat of dissociation of $X_2$

$\quad L_{Pb}$  =  the latent heat of Pb.

$\quad L_{PbX}$  =  „   „   „   „ PbX.

$\quad L_X$  =  „   „   „   „ X.

The thermo-chemical data involved in this equation were taken from the tables of Landölt and Börnstein. They are tabulated below together with the various values for R.

TABLE 1.   PbS

| Limit of Absorption. | R K cal | Q K cal | $\frac{1}{8}$ DS.* K cal | L$_{Pb}$ K cal | L$_S$ K cal | L$_{PbS}$ K cal |
|---|---|---|---|---|---|---|
| 3500A | 80·2 | | | | | |
| | | 22 | 56·7 | 44·5 | 15 | 55·6 |
| 2450A | 116·7 | | | | | |

The value 55·6 K cal. for LPbS was obtained with the help of the relation $L = R \dfrac{T_1 T_2}{T_2 - T_1} \log_e \dfrac{P_2}{P_1}$ from the following vapour pressure data given by Schneck and Albers*

| t | p | t | p |
|---|---|---|---|
| 850°C | 2 mm | 968°C | 10·5 mm |
| 917°C | 4 mm | 995°C | 17 mm |

The first reading for vapour pressure gives widely different values for the latent heat when combined with the others hence it was discarded. The other three gave consistent values: the mean being 55·6 K cal.

TABLE 2.   PbO

| Limit of Absorption | R K cal | Q K cal | $\frac{1}{2}$ DO$_2$ K cal | L$_{Pb}$ K cal | L$_{PbO}$ K cal |
|---|---|---|---|---|---|
| 3000A | 95·8 | | | | |
| | | 52·7 | 64 | 44·5 | ? |
| 2240A | 127·7 | | | | |

No vapour pressure data for PbO are available. Hence its latent heat cannot be calculated.

PbS   Applying the equation (1) to PbS we get

$$80·2 = 22 + 56·7 + 15 + 44·5 - L_{PbS}$$

or   L$_{PbS}$ = 58·0 K cal.

*S$_2$ + 90 = 2S
4S$_6$ − 29 = 3S$_8$
S$_6$ + 64 = 3S$_2$

S$_8$ + 455 = 8S.

These data are taken from the tables of Landolt and Bornstein.

This agrees well with the value obtained from vapour pressure data, *viz.*, 55·6 K cal. The second cut is 1·59 volts higher than the first and may correspond to the excitation energy of sulphur from the state $3P_0$ to $1D_2$. This has been found by Christie and Norde [a] to be 1·6 volts.

PbO Using the relation (1) we get $95·3 = 52·7 + 64 + 44·5 - L_{PbO}$ $L_{PbO}$ comes out to be 66 K cal. This is a probable value since the latent heats of oxides are generally higher than those of the corresponding sulphides.

The difference between the first and the second cut is 32·4K cal; which may correspond to the energy required to excite the oxygen atom from $3P_0$ state to $^1D_2$ state; which is 1·9 volts.

## CONCLUSION

In the normal state the molecule may be assumed to be $Pb^{++} X^{--}$ extending Frank's view as suggested by P. K. Sen Gupta. O has the same configuration as Neon and S as Argon. The ground state of $Pb^{++}$, which has the same configuration of electrons as Mercury is $^1S_0$. The salts should be both diamagnetic.

Corresponding to the fact that the molecules are quite stable the potential energy curve will have a deep minima. It will be of the type L represented in the figure 1.
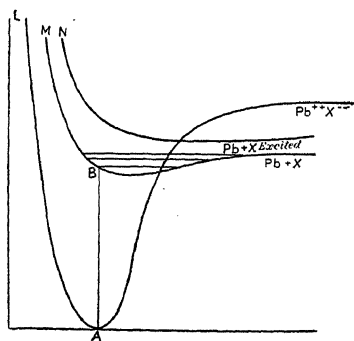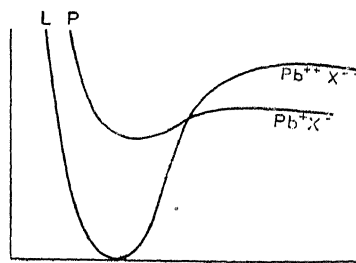


Fig. 1          Fig. 2

By absorption of light the molecule will pass along AB to the next higher curve M without change of nuclear distance in general. This is in accordance with Frank-Condon principle. This will thus result in the dissociation of the molecule into $Pb + X$. The presence of a few bands at the beginning of the continuous absorption may be due to the fact that the curve M may also have a flat minima. The greatest value of R will correspond to the transition along AB when the molecule passes from the lowest vibrational level of the normal state. The next higher curve N represents the dissociated molecule so that X is excited to some upper level. There may also be a state P (Fig. 2) of the molecule $Pb^+ X^-$ with a minima and the transition from

L to P will give rise to band absorption. Attempts to search for these probable bands are being made.

On the assumption that the normal state is $Pb^{++} X^{--}$ the binding must obviously be electrostatic. A study of the lower half of Born cycle seems to lend some support to this view.

Here E = the lattice energy of the crystals.

$I_1$ = the ionisation potential of Pb

$I_2$ = the ionisation potential of $Pb^+$.

$I_e$ = two electron affinity of X
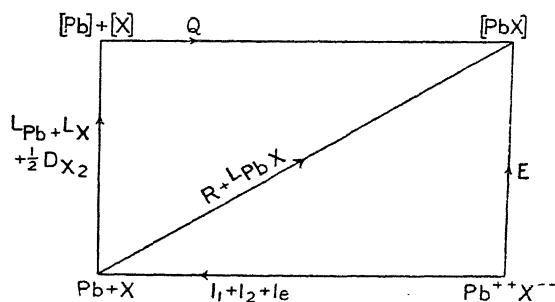


Fig. 3

All other symbols have already been defined.

From the lower half of Born cycle we get

$$E - (I_1 + I_2 + I_e) = R + L_{PbX} \qquad . \qquad . \qquad . \qquad . \quad (2)$$

## CALCULATION OF E

The value of E for PbS has been calculated by Born and Gerlach[6] with the help of the formula

$$E = K \cdot \frac{n-1}{n} \sqrt[3]{\rho_{1M}}$$

where K = a constant involving Madelungs constant

$n$ = repulsion exponent

$\rho$ = density

M = molecular weight.

The repulsion exponent $n$ is given as $n = 1 + 8{\cdot}00 \times 10^{-14} \dfrac{1}{X} \left(\dfrac{M}{P}\right)^{\frac{4}{3}}$; X being the compressibility.

The lattice energy of PbS whose crystals are cubical of Sodium chloride type has been found by these authors as 636K cal.

The lattice energy of PbO unfortunately cannot be calculated; since there is no data for its compressibility.

The $^3P_0$ state of Pb = 59810[7]

$^2P_{\frac{1}{2}}$ state of $Pb^+$ = 121256[8]

Hence    $I_1 + I_2$ = 517K cal.

The double electron affinity of S has been calculated by Samuel and Lorentz[9] and they find it as $-30$ K cal.

The left hand side of equation (2) thus gives

$$636 - (517 - 30) = 149\text{K cal}$$

while the right hand side gives $R + L_{PbS} = 137'1$K cal.

The agreement is fairly good considering the uncertainties involved in the calculation of the lattice energy and the electron affinity of PS.

My thanks are due to Prof. M. N. Saha, F.R.S., for his kind interest in this work.

## SUMMARY

1. The absorption spectra of PbO and PbS has been studied. There is a continuous absorption in both the cases showing that the photo-chemical reaction results in the dissociation of the molecules into two free atoms.

2. Retransmission in each case is interpreted as due to the excitation of sulphur or oxygen atom from the normal state $^3P_0$ to the metastable state $^1D_2$.

3. The latent heat of PbS is found to be 58 0 K cal; agreeing well with the value obtained from vapour pressure data, viz., 55'6 K cal. The latent heat of PbO is found to be 66 K cal.

4. A study of the Born cycle lends some support to the view that in the normal state the molecules are $Pb^{++}X^{--}$.

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# THE ABSORPTION SPECTRA OF THE VAPOURS OF THE LOWER CHLORIDES OF ELEMENTS OF THE FIFTH GROUP OF PERIODIC TABLE

## By HRISHIKESHA TRIVEDI

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The object of the present paper is to report experiments on the absorption spectra of the trivalent halides of elements of the fifth group, *viz.*, P, As, Sb and Bi. As is well known they form pentahalides as well as trihalides. All available information about them is collected in the following table.

TABLE I.

| Element \ Compound | Trichloride | Tribromide | Triiodide | Pentachloride | Pentabromide |
|---|---|---|---|---|---|
| Phosphorus | $PCl_3$ <br> Colourless liquid b.p. 76°C m.p. —112°C. | $PBr_3$ <br> Colourless liquid b.p. 170·8°C m.p. —40°C | $PI_3$ <br> Dark red crystals m.p. 61°C. | $PCl_5$ <br> White crystalline solid, sublimes m.p. 148°C b.p. 162°C | $PBr_5$ <br> Yellow crystalline solid, decomposes on heating b p. 106°C |
| Arsenic | $AsCl_3$ <br> Colourless oily liquid b.p. 130·2°C m.p.—13°C | $AsBr_3$ <br> Colourless crystalline solid m.p. 31°C b.p. 221°C | $AsI_3$ <br> Red hexagonal crystals m.p. 146°C | $AsCl_5$ <br> Decomposes into $AsCl_3$ and $Cl_2$ above —25°C | $AsBr_5$ <br> ... |
| Antimony | $SbCl_3$ <br> White crystalline solid. m.p. 73·2°C b.p. 223·5°C | $SbBr_3$ <br> White deliquiscent needles m.p. 73°C b.p. 280°C | $SbI_3$ <br> Melting point of the stable form is 171°C | $SbCl_3$ <br> Yellow mobile liquid b.p. 140°C | $SbBr_5$ |

TABLE I—(*continued*)

| Compound / Element | Trichloride | Tribromide | Triiodide | Pentachloride | Pentabromide |
|---|---|---|---|---|---|
| Bismuth ... | $BiCl_3$ White crystalline solid m.p. 227°C b.p. 447°C | $BiBr_3$ Golden yellow crystals. | $BiI_3$ Black powder. | $BiCl_5$ | $BiBr_5$ |

The question now arises as to whether the trihalides or the pentahalides can be regarded as saturated compounds Let us first take as an illustrative example, the chlorides of phosphorus.

$PCl_3$ is diamagnetic, we may suppose that it has the constitution $P^{+++}$ $Cl^{-s}$. Each $Cl^-$ ion is diamagnetic, and $P^{+++}$ has the constitution $1s^2 2s^2 2p^6 3s^2$; hence $P^{+++}$ is also diamagnetic

$PCl_5$ is also diamagnetic. We may suppose that it has the constitution $P^{+5}$ $Cl^{-5}$. $P^{+5}$ has the inert gas constitution $1s^2 2s^2 2p^6$. If the above hypothesis be true, both $PCl_3$ and $PCl_5$ should show continuous absorption, as in the case of saturated halides of different valency Chlorides of other elements in this group of periodic table will also behave likewise.

The calculation of the atomic heat of formation of $MHa_3$ out of one M atom and 3 Ha atoms as expressed by the relation

$$M + 3\ Ha = MHa_3 + R$$
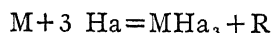
is a matter of some difficulty; for usually the elements of this class, *viz.*, P, As, Sb and Bi vaporise in the polyatomic state. Preuner and Brockmöller[1], in their extensive studies on the vapour pressure and vapour density of P and As find that at ordinary temperatures they vaporise as $P_4$ and $As_4$ which however break up into $P_2$ and $As_2$ as higher temperatures are reached. At still higher temperatures, the diatomic molecules may be broken up into atoms. The processes may be thus represented

$$[\ P\ ] = P_4 + \lambda$$
$$P_4 = 2P_2 - D_1$$
$$P_2 = 2P - D_2$$

According to Preuner and Brockmöller[1]

$D_1 = 31\cdot5$ K cals; $D_2 = 45\cdot5$ K cals and $\lambda = 12\cdot6 \times 124 = 15$ K cals.

Let S be the heat of vaporisation from the condensed state to the atomic state. Then we have

$$S = \frac{\lambda + D_1 + 2D_2}{4} = \frac{15 + 31 \cdot 5 + 91}{4} = \frac{138}{4} = 34 \cdot 5 \text{ K cals.}$$

Then

$$R = Q + S + \tfrac{3}{2} D_{Ha_2} - \lambda_{MHa_3}$$

In the case of $PCl_3$

$$Q = 75 \cdot 3 \text{ K cals ; } S = 43 \cdot 5 \text{ K cals; } \tfrac{3}{2} D_{Cl_2} = 86 \text{ K cals ; } \lambda_{MHa_3} = 9 \cdot 3 \text{ K cals.}$$

$$R = 186 \cdot 5 \text{ K cals.}$$

The Table II has been compiled as shown below.

As regards Sb and Bi the dissociation has not been well studied. But probably they also vaporise as $Sb_4$ and $Bi_4$. For Bismuth there is some indirect evidence. The absorption spectrum of Bi vapour has been studied by Barratt and Bonar[2] and has been found to consist of two indistinct systems of bands. One of them has been attributed to $Bi_2$ molecule and from the convergence limit of this band the heat of dissociation of $Bi_2$ molecule has been calculated amounting to 18·5 K cals. The other band system has been attributed to a molecule of greater complexity, probably $Bi_4$; but unfortunately, it has not been analysed and we do not know the heat of dissociation of $Bi_4$.

Since all these molecules belong to the same group of periodic table we expect that the nature of their binding forces will be similar. As we know these values for a few of them we can get them for the others by interpolation. The interpolated values give at least the region where the correct values should lie. We take these values for the calculation of R in respective cases. The extrapolated values and their justification is to be seen from Tables 1, 2 and 3.

<div align="center">TABLE 1</div>

| Reaction $M_2 \longrightarrow 2M$ | Heat of dissociation ($D_2$) | Difference |
|:---:|:---:|:---:|
| $P_2 \longrightarrow 2P$ | 45·5 K cals | |
| $As_2 \longrightarrow 2As$ | 38 K cals | 7·5 K cals |
| $Sb_2 \longrightarrow 2Sb$ | (28) K cals | (10) K cals |
| $Bi_2 \longrightarrow 2Bi$ | 18·5 K cals | (9·5) K cals |

F. 4

TABLE 2

| Reaction $M_4 \longrightarrow 2 M_2$ | Heat of dissociation ( $D_1$ ) | Difference |
|---|---|---|
| $P_4 \longrightarrow 2 P_2$ | 31·5 K cals | 6·5 K cals |
| $As_4 \longrightarrow 2 As_2$ | 25 K cals | (9) K cals |
| $Sb_4 \longrightarrow 2 Sb_2$ | (16) K cals | (8·5) K cals |
| $Bi_4 \longrightarrow 2 Bi_2$ | (7·5) K cals | |

TABLE 3

| Substance | Heat of dissociation ( $D_2$ ) | Heat of dissociation ( $D_1$ ) | Difference |
|---|---|---|---|
| Phosphorus | 45·5 K cals | 31·5 K cals | 14 K cals |
| Arsenic | 38 K cals | 25 K cals | 13 K cals |
| Antimony | (28) K cals | (16) K cals | (12) K cals |
| Bismuth | 18·5 K cals | (7·5) K cals | (11) K cals |

TABLE II

N.B.—The values enclosed in brackets ( ) are uncertain because of the above interpolation.

| Substance | Long wavelength limit $\nu_m$ in °A | $Q_m = \dfrac{Nh\nu_m}{J}$ in K cals | Heat of reaction required to convert solid element into monatomic vapour in K cals per gm. atom "L" | Heat of formation of the salt in K cals per mole "Q" | Heat of vaporisation of the salt in K cals per mole "λ" | $\dfrac{R}{3}$ in K cals | $Q_m - \dfrac{R}{3}$ in K cals |
|---|---|---|---|---|---|---|---|
| Phosphorus Trichloride | 2957 | 96·2 | 34·5 | 75·3 | 9·25 | 62·5 | 33·7 |
| Arsenic Trichloride | 5466 | 82·1 | 26·5 | 71·4 | 6·7 | 59·4 | 22·6 |
| Antimony Trichloride | 3256 | 87·3 | (27·6) | 91·4 | 11·05 | (65·0) | (22·3) |
| Bismuth Trichloride | 3656 | 77·2 | (24·2) | 90·6 | 18·3 | (61·2) | (16·0) |

## EXPERIMENTAL PROCEDURE

Of the four substances examined two were liquids and the other two were solids whose boiling points were less than 500°C. Two kinds of absorption vessels were used for producing the vapour and studying the absorption. For the solids (i.e., BiCl₃ and SbCl₃) a pyrex glass furnace of the design shown in the diagram below was used   (Fig. 1).

A is a pyrex glass tube of about one inch in diameter.    BB are water-jackets employed for preventing the hot vapour from coming from the inside of the tube and depositing on the quartz windows C. The substances could be introduced in through the side tube D which also served for the connection to the vacuum pump. The furnace



Fig. 1

was heated by winding manganin wire round it and passing high electric current through it.
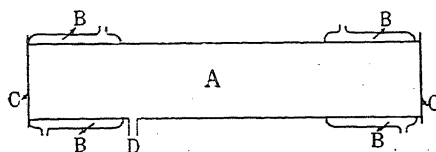
For the liquid the furnace took the form of a long tube of glass of about an inch in diameter closed at its ends by quartz windows. Two side tubes provided with stop-cocks were attached to it. One of these tubes served for the connection to the vacuum pump. The other ended in a glass bulb of about 50c.cs. in capacity which was provided with a second stop cock for connecting the bulb to the atmosphere   (Fig. 2).
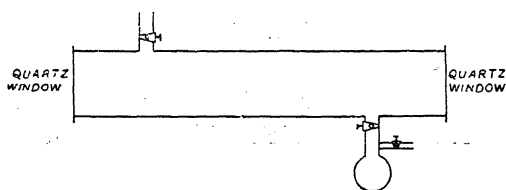


Fig. 2

The liquid under investigation, could be introduced into the side bulb. The vapour pressure in the long tube was varied by placing the bulb in baths of varying temperatures.

The vapour pressures could be measured in the first case by noting the temperature to which the furnace had been raised and taking from the tables (given in Mellor's 'Comprehensive Treatise in Inorganic and Physical Chemistry') the value of the saturation vapour pressures of the substance at that temperature. The temperature of the furnace was known by calibrating it in terms of the heating current when it had come to a steady state of temperature. In practice the steady state was brought about by heating it for at least ten minutes with constant current. Each photograph was taken only when the furnace had been heated by a definite electric current for about 30 minutes. In case of liquids the vapour pressure was measured by introducing a manometer on the pump side of the furnace.

The source for the continuous absorption was the Hydrogen tube run by a high current transformer at a current density of 100 M.A. The photographic plates used were Ilford Process plates.

### DISCUSSION

We find (cf. Table II) that the energy of optical dissociation is in each of the compounds greater than the one-third of thermochemical value but less than two-thirds of it. Thus although one chlorine atom is shaken off from the molecule by the incident radiation, the energy expended is not strictly equal to that present in a single bond of the molecule.

Although a definite interpretation of these results cannot be offered unless more data accumulates, yet a few observations may well be made.

When a quantum of light, of energy $h\nu$ ($\nu$ being the long wavelength limit of the absorption spectrum) comes into contact with the molecule, it is absorbed by the latter. On its absorption it excites the electronic structure of the molecule which now corresponds to the state represented by a dipole $MCl_2 - Cl^*$. Here one electron passes over from the chlorine ion to the remaining portion of the molecule and we get dissociation product of the molecule, $i.e.$, a chlorine atom and a dichloride of the metal. It is found that the energy corresponding to the long wavelength limit of absorption is greater than the value for $\frac{R}{3}$ in the case of all these chlorides. Franck in a recent note to the 'Naturwissenschaft' suggests that this difference is due to the vibrational energy given to the dichloride, which is obtained on photo-dissociation. The difference found in the present case is of the order of twenty to thirty K cals. This order of magnitude is too big to be due to vibrational changes only. It seems probable that this extra energy is involved in the electronic structure of the dichloride formed. The dichlorides are found as definite compounds, but unfortunately there does not exist any data about their heats of formation. This assumption is plausible as the electronic structure of the dichloride in the undissociated trichloride is not the same as that associated with the free dichloride. To bring about this change in the electronic structure some energy is obviously required. It manifests itself in the difference between $\frac{R}{3}$ and $Q_m$

The results may also be explained from a new hypothesis put forward by M. S. Desai of this laboratory (the hypothesis is yet unpublished for want of confirmatory experimental support). Desai considers the strength of each bond separately, making an assumption that if the fully developed compound be $MX_n$ the unsaturated state $MX_m$ ($m < n$) will have a binding strength $\frac{m}{n}$ times the fully developed compound. He calculates the strength

of each bond separately and adding them together equates it to the total thermo-chemical energy R and obtains the fraction which should give the beginning of absorption. He gets, for

MX$_4$ the limit of absorption to correspond to $\frac{2}{5}$ R

MX$_3$ ,, ,, ,, ,, $\frac{1}{2}$ R

MX$_2$ ,, ,, ,, ,, $\frac{2}{3}$ R

MX ,, ,, ,, ,, R

In the present case the absorption limit should be obtained by $\frac{R}{2}$ and not $\frac{R}{3}$ as given by Datta and Saha[3]. The agreement is seen from the following figures:—

TABLE 4

| Substance | $Q_m$ (observed) K cals | $\frac{R}{2}$ K cal s | $\frac{R}{3}$ K cals |
|---|---|---|---|
| Phosphorous Trichloride ... | 96·2 | 94·0 | 62·1 |
| Arsenic Trichloride ... | 82·1 | 86·5 | 57·4 |
| Antimony Trichloride ... | 87·3 | (97·5) | (65·0) |
| Bismuth Trichloride ... | 77·2 | (92·2) | (61·2) |

The agreement is tolerable in the case of PCl$_3$ and AsCl$_3$. In the case of other two compounds nothing can be said either for or against Desai's hypothesis, as the heats of dissociation of Bi$_1$, Sb$_1$, and Sb$_2$ are not known. The value of R calculated by the help of the extrapolated values for those quantities cannot be accurate.

ACKNOWLEDGMENTS

and to Mr. Bhola Nath Ghosh research scholar Patna for rendering me material help during my stay there.

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# A NOTE ON THE VAPOUR PRESSURE OF ZINC BROMIDE

By M. S. Desai

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The purpose of this note is to correct a mistake that has been discovered after the publication of the paper on the same subject by the author,[1] in the last issue of the Bulletin.

In the said paper it is assumed that,

$$C - C_p = 3R - \frac{5}{2}R$$

$$= R/2$$

where C is the specific heat of the solid and $C_p$ that of the vapour at constant pressure, but this is only true in the case of monatomic vapour. In the case of $Zn Br_2$, where the molecule is tri-atomic it requires modification.

$$C = 3R; \text{ and } C_p \text{ is given by } C_p - C_v = R$$

and

$$C_v = C_{rot} + C_{trans} + C_{osc.}$$

$$= \frac{3}{2}R + \frac{3}{2}R \quad \text{(neglecting the oscillation at low temp.)}$$

$$= 3R$$

therefore $C_p = 3R + R = 4R$

and $C - C_p = 3R - 4R$

$$= -R$$

Thus Clausius' equation $\lambda = RT^2 \dfrac{d\ln P}{dT}$ becomes,

$$\ln P = -\frac{\lambda_0}{RT} - \frac{C - C_p}{R} \log T + k$$

or $\log_{10} P = \dfrac{-\lambda_0}{2 \cdot 3RT} + \log_{10} T + k'$

This is of the form,

$$\log P = -\frac{A}{T} + \log T + B$$

Evaluating the constants A and B from the experimental data we have,

$$\left.\begin{array}{ll} A = & 5639\cdot781 \\ \text{and} \quad B = & 9\cdot066 \end{array}\right\} \qquad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(A)}$$

Thus the vapour pressure equation for $Zn\,Br_2$, between 300° to 400°C becomes,

$$\log_{10} P = \frac{-5639\cdot781}{T} + \log_{10} T + 9\cdot066$$

And the latent heat of evaporation

$$\lambda_0 = -4\cdot554\,A$$
$$= 4\cdot554 \times 5639\cdot781$$
$$= 25\cdot68 \quad \text{k cals} \qquad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(B)}$$

instead of 27·60 k cals as calculated before.

My thanks are due to Mr. B. N. Srivastava of our Department for pointing out the mistake.

*Reference.*

[1] M. S. Desai, *Bul. Acad. Sci.,* U. P., Allahabad, *2,* 124, 1933.

# ON THE TREMATODE PARASITES OF A RANGOON SILUROID FISH *CLARIAS BATRACHUS* (LINNAEUS 1785)

By R. C. CHATTERJI

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In course of an investigation on the parasites of the common food fish of Rangoon, there were obtained from thirty *Clarias batrachus* (Linnæus 1785) a large number of trematodes which fall into three distinct groups. Two of these are members of the family Lepodermatidae Odhner 1911—one representing a new species and the other a new genus : the third is markedly different from the others and constitutes a new genus of a new sub-family belonging to the family *Acanthostomidae* Poche 1926.

## Astiotrema Spinosa n. sp.

These trematodes do not appear to be common : out of the thirty fish examined only three were found to be infected, with 35, 9, and 1 parasites respectively. In hosts one and three the parasites were obtained from the intestine and in host two from the posterior part of the stomach. Body when

F. 5

contracted, pegshaped, with a much broader anterior end: when elongated margins more or less parallel, with rounded anterior and posterior ends. In the extended condition the anterior end is greatly narrower ending in a blunt point. Body musculature more strongly developed between suckers, so that, when the animal contracts, the two suckers lie very close to each other. Cuticle covered with sharp pointed spines arranged in transverse rows, the spines of each row alternating with those of the preceding and succeeding rows. Spines become progressively denser on the surface from the posterior to the anterior part of the body. Body length 1˙3*—3, maximum breadth 0˙4 0˙58, with a much smaller variation than in the length. Suckers powerful. Ventral sucker in first third of the body, circular in outline, approximately 0˙185 in diameter. Oral sucker, slightly smaller than ventral, 0˙18 × 0˙16. Genital opening closely anterior to ventral sucker. Small prepharynx present. Pharynx spherical, 0˙08 in diameter in extended specimen. Oesophagus moderately long, from $1-2\frac{1}{2}$ times length of pharynx. In rare cases, *i.e.*, in fully extended condition its length extends to four times the length of pharynx. Intestinal bifurcation between the two suckers, its position changing with the degree of expansion. Intestinal caeca more or less straight, terminating a little anteriorly to posterior end of body.

Testes rounded, large, usually equal, 0˙16—0˙28 in diameter, situated obliquely one behind the other in posterior half of body just behind the middle, occupying most of the space between the caeca. In a few preserved and mounted specimens, however, the testes were found to be elliptical and broader than long. Cirrus sac large, extending much behind the ventral sucker as far as ovary, 0˙23—0˙44 in length, posteriorly saccular, almost entirely filled by the large vesicula seminalis and continuing anteriorly into a tubular structure. Parsprostatica tubular and long separated from vesicula seminals by constriction. Ductus ejaculatorius small, continuing into a small cirrus. Male opening shallow, genital atrium to the right of the female opening.

Ovary spherical, 0˙13—0˙17 in diameter, approximately in median line, much posterior to ventral sucker except in contracted specimens. Receptaculum seminis large, pearshaped and elongated transversely, joining oviduct near ovary. Coils of uterus rarely overlapping gut diverticula except in the part posterior to testes. Vitellaria composed of numerous follicles, scattered without any definite arrangement along lateral margins of body overlapping intestinal caeca from posterior margin of ventral sucker to anterior margin of posterior testis or sometimes to posterior margin of the latter, in which case the distance between the two testes was considerably less than normal and that from the posterior testis to posterior end of the body correspondingly

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* All measurements are in millimetres.

increased, indicating an anterior displacement of that testis. The follicles greatly extend inwards to the median line in the region between ovary and anterior testis   Eggs numerous, with a yellowish-brown shell, 0·027 × 0·0114.

.The present species has a small protrusible cirrus and a large cirrus sac extending much behind the ventral sucker which is characteristic of the genus Astiotrema  It thus agrees with the definitions given by various investigators ⟨Looss, Odhner, and Mehra). The Burmese form differs from *Astiotrema loossii* Mehra 1930 in the relative size of its suckers, in the absence of lobed margins to the testes and ovary, and in the extent of vitellaria and intestinal caeca.   From *A. impletum* Looss 1899, *A. monticellii* Stossich 1904 and *A. elongatum* Mehra 1930 it is separated by a difference in the position of the intestinal fork and by the extent of intestinal caeca and vitellaria.   It is closer to *A. reniferum* Looss 1899 but differs from that species in the extent of the intestinal caeca and vitellaria.   These differences necessitate the creation of a new species, for which the name *Astiotrema spinosa* is proposed.   This is the second species of the genus Astriotrema obtained from fish, the first' *Astiotrema impletum* Looss 1899, being recorded from *Tetradon fahaka.*

## Ganada clariae n. gen., n. sp.

This species is common : out of the fish examined nineteen were infected, the number of parasites from each fish ranging from 1·63, with an average of of 10—15. Body, when contracted, oval, with much broader anterior end : when extended, cylindrical, with rounded ends.   Length 1·53—2·8 maximum breadth 0 3—0·4.  Cuticle with small spines, progressively denser from posterior to anterior part of body. Suckers powerful, ventral slightly larger than oral, 0·133 — 0·18 and 0·114—0·164 in diameter respectively.  Genital pore immediately in front of ventral sucker to the left of the median line and some distance behind intestinal bifurcation.  Prepharynx short, 0·04—0·046 in length.  Pharynx 0·08— 0·14 in diameter.  Oesophagus 0·027—0·061 in length.  Intestinal caeca wide, comparatively broad anteriorly and extending almost to posterior end of body.

Testes median, in the third quarter of the body, the distance separating the two differing in different specimens.  Posterior testis slightly bigger than anterior, approximately 0·152—0 21 and 0·137—0·18 in diameter respectively. Genital atrium small, 0 02—0·04 in diameter.  Cirrus sac somewhat tubular, slightly semilunar, 0·234—0·4 in length, dorsal to ventral sucker extending slightly posteriorly to it.  Vesicula seminalis divided into internal and external portions, the latter lying close to ovary.  Pars prostatica small, near anterior margin of ventral sucker.  Cirrus small.  Male opening to the right side of the female.

Ovary approximately spherical, 0·114—0·162 in diameter, lying in middle third of body.  Vitellaria composed of numerous, closely crowded big follicles

along lateral margins of body, more densely crowded in post-testicular region than in pre-testicular. Uterus much coiled, the loops running transversely and passing between testes. Eggs numerous, thin-shelled, approximately 0·018 × 0·012. Excretory bladder Y-shaped and typical of the family Lepodermatidae Looss 1899.

The parasite agrees with the characters of the subfamily Lepodermatinæ Looss 1899, but differs from all the genera included in it in the presence of an external vesicula seminalis. In the absence of a receptaculum seminis it resembles *Lepoderma* Looss 1899 and Haplometra Looss 1899 but differs from the other genera. The tandem position of the testes and the position of the cirrus sac further separate it from *Lepoderma* Looss 1899. From Haplometra Looss 1899 it differs in the rudimentary nature of its oesophagus and the pronounced coiling of the uterus in addition to the presence of its characteristic external vesicula seminalis. By its possession of the latter organ it exhibits a certain affinity with the genus *Leptophallus* Luhe 1909, but this similarity does not extend to other characters. A new genus is therefore created for the reception of these parasites, for which is proposed the name *Ganada* with *Ganada clariae* as the type genus and species.

### Diagnosis of the genus *Ganada*, n. gen.

Lepodermatidæ: Lepodermatinae. Cuticle with spines. Suckers almost spherical, unequal, Prepharynx and pharynx present. Oesophagus very short. Genital pore left of the median line, anterior to ventral sucker. Intestinal caeca extending to hinder part of body. Testes post-ovarian and median, the posterior larger than the anterior. Ovary smaller than testes. Cirrus sac semilunar and median, extending dorsally over ventral sucker. Vesicula seminalis divided into internal and external vesiculæ seminales. Receptaculum seminis absent. Vitellaria with closely packed follicles, extending from behind ventral sucker to posterior end of body. Uterus much coiled, nearly reaching posterior end of body and containing numerous eggs. Excretory bladder Y-shaped and typical of the sub-family.

### *Masenia collata n. gen., n. sp.

On examination of thirty fish, eighteen were found infected with these parasites, in the intestine or posterior part of the stomach, the number in each case ranging from 1 — 390.

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\* From *masen*, the Chingpo for spine or thorn.

Body club-shaped, 0·7—1 in. length with a maximum breadth of 0·24—0·36. Cuticle for anterior three-fourths of body armed with small sharp spines which become progressively denser from the posterior to the anterior part of the body. In addition to body spines, approximately 53 oral spines are present around the oral sucker, arranged in two regular rows—one above the other. Suckers very powerful. Oral larger than ventral, 0·12—0·17 × 0·11—0·15, funnel-shaped, extending for a considerable distance within the body. Ventral sucker circular, 0·1—0·13 in diameter, lying in anterior half of body. Pre-pharynx short, approximately 0·02—0·045 in length. Pharynx 0·04—0·54 × 0·025—0·042. Oesophagus small, dividing immediately anteriorly to ventral sucker into two wide caeca which, maintaining approximately the same width throughout, extend to the level of the posterior testis.

Testes approximately equal and spherical, 0·07—0·1 in diameter, lying close to each other in middle third of body. Genital atrium in form of a shallow depression close behind oral sucker. Cirrus sac large, of greater length than half the length of the body, divisible into two distinct portions, a broad basal part and a long narrow coiled tubular structure, the latter fitting into the neck of the former. Vesicula seminalis mostly within saccular part of cirrus sac, divided by a contriction into a smaller proximal and a large distal portion, and extending for a short distance in its tubular part. Pars prostatica and ductus ejaculatorius enclosed within narrow tubular part of cirrus sac. (In Fig. 5 not visible being hidden by gland cells). Cirrus small and in most of the fixed specimens distinctly portrudes out of the body in region of oral sucker.

Ovary immediately behind ventral sucker, approximately spherical, 0·064—0·12 in diameter, slightly bigger than testes. Receptaculum seminis large, posterior to ovary, often obscured by the large number of eggs in its vicinity. Vitellaria composed of follicles extending from anterior margin of ventral sucker to middle of posterior testis. Uterus voluminous, the convolutions occupying practically the whole body posterior to intestinal bifurcation and too closely crowded for the individual coils to be observed. Passing backwards from its origin behind the ventral sucker it forms a double sinuous course in the post-acetabular region. It then turns forward and, still with a slightly sinuous course, opens into the genital atrium immediately behind the oral sucker. Eggs numerous, oval, with a yellowish shell approximately 0·02 × 0·012. Excretory bladder broad and tubular, extending anteriorly to posterior testis; cornua not visible probably owing to the crowding of genital glands, cirrus sac and ventral sucker.

The peculiar oral spines and the funnel-shaped oral sucker of *Masenia collata* n. sp. are characteristic of some of the genera of the family *Acanthostomidae* Poche 1926 (Syn. *Acanthochasmidae* Nicoll (1914) to which it exhibits closer relationship than to any other family. The presence of a well-developed

cirrus sac in *Masenia*, however, separates it from all the genera of the *Acanthostomidae* Poche 1926 except those included in the sub-family *Anoictostominae* Nicoll 1914. The affinities, however, are very close with *Anoictosoma planicolle* Rud. 1819) as exhibited in the following characters : —

1. Large funnel-shaped oral sucker.
2. Presence of oral spines.
3. Size of suckers.
4. Well-developed cirrus sac enclosing large vesicula seminalis.
5. Ovary close behind ventral sucker.
6. Uterine coils mainly posterior to testes.

On the other hand, the differences between them are so great that it is not possible to include *Anoictosoma planicolle* (Rud. 1819) and my species in the same genus. In most of the genera of the family *Acanthostomidae* Poche 1926, the cirrus sac has been recorded to be absent and in some cases where it is present as in *Anoictosomum* Stossich 1899 it does not extend much in front of the anterior margin of ventral sucker. Masenia n. gen. has a long tubular coiled cirrus sac which remarkably differs in shape and size from that of all the genera of the family *Acanthostomidae* Poche 1926. Further, the genital opening in this family lies immediately anterior to ventral sucker but in *Masenia* n. gen. it has become shifted much forward and occupies a position dorsal to oral sucker. It is therefore considered necessary to create a new genus *Masenia* with *M. collata* as the type species. Though the genus shows closer relationship with the sub-family *Anoictostominae* Nicoll 1914 than *Acanthostominae* there does not seem to be any doubt that it belongs to a new sub-family *Maseniinae* on account of two important characters, *i.e.*, the form and size of the cirrus sac and the position of the genital pore.

Key to the sub-families of the family *Acanthostomidae* Poche 1926 :—

1. Cirrus sac absent ... *Acanthostominae.*
   Cirrus sac present ... 2.
2. Genital opening close in front of
   ventral sucker ... *Anoictostominae* Nicoll 1914.

Genital opening far in front of ventral
sucker and near oral sucker... *Maseniinae* n. sub. fam.

Diagnosis of the sub-family *Maseniinae* n. sub. fam. :—

Acanthostomidae: Body small. Cuticle spinose. Suckers strongly developed: oral sucker funnel-shaped, much larger than ventral, with strong spines arranged in two rows. Prepharynx present. Pharynx well developed. Oesophagus of moderate length. Cirrus pouch long and coiled, divisible into a basal saccular part and a distal tubular portion nearly reaching anterior end of body. Vesicula seminalis large, its basal portion saccular. Cirrus small and unarmed, Testes post-acetabular, post-ovarian, nearly spherical. Re-

ceptaculum seminis present. Vitelline glands with large follicles extending between ventral sucker and posterior testis. Uterus very voluminous, convoluted, occupying greatly hinder part of the body behind testes. Excretory bladder tubular, extending to posterior testis. Eggs numerous and oval. Parasites of siluroid fish (*Clarias batrachus*).

Type genus *Masenia* n. gen.

Type-species *M. collata* n. gen., n. sp.

## ACKNOWLEDGMENT

The author has great pleasure to express his sincere thanks to Dr. H. R. Mehra and Professor F. J. Meggitt for their kind help and valuable suggestions. Thanks are also due to Professor D. R. Bhattacharya for kindly providing facilities to complete this work in the Zoology Department of the Allahabad University.

## EXPLANATION OF PLATES

Fig. 1.  *Astiotrema spinosa*—Ventral aspect (camera lucida drawing).

Fig. 2.  *Ganada clariae* n. gen., n. sp.—Ventral aspect (camera lucida drawing).

Fig. 3.  *Ganada clariae* n. gen., n. sp. — Horizonto-Longitudinal section.

Fig. 4.  *Masenia collata* n. gen., n. sp.—Ventral aspect (camera lucida drawing).

Fig. 5.  *Masenia collata* n. gen., n. sp.—anterior part of the body showing cirrus sac.

## LETTERING TO FIGS. 1—5

c. cirrus, c. s. cirrus sac, e, s. v. vesicula seminalis externa, g. o genital opening, i. c. intestinal caecum, i. s. v. vesicula seminalis interna, oes. oesophagus, o. s. oral sucker, ov. ovary, p. g. prostate gland cells, ph. pharynx, r. s. receptaculum seminis, s. g. shell gland, s. v. vesicula seminalis, t₁. anterior testis, t₂. posterior testis, ut. uterus, vit. vitellaria, v. s. ventral sucker.

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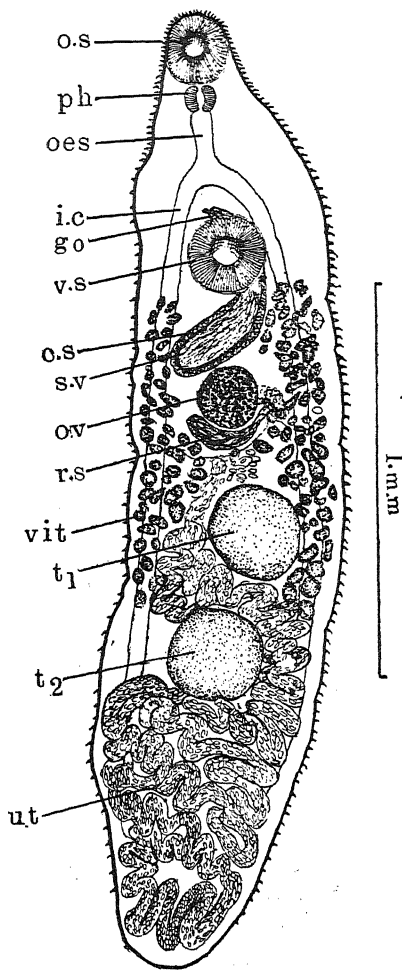
FIG 1.—*Astiotrema spinosa*, n. sp.,
ventral aspect.
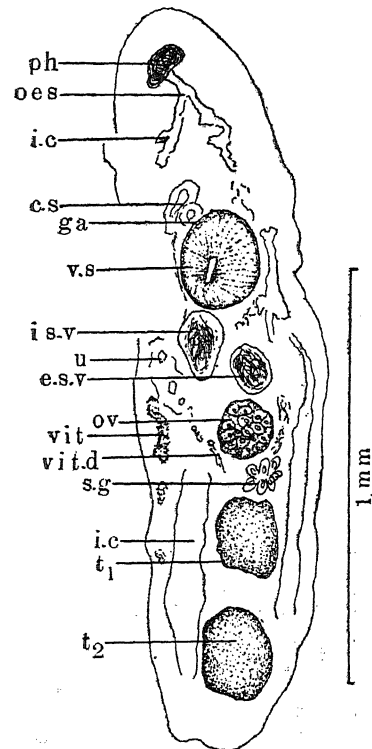


FIG 3.—*Ganada Clariae*, n. gen.,
n. sp., horizonto-longitudinal section
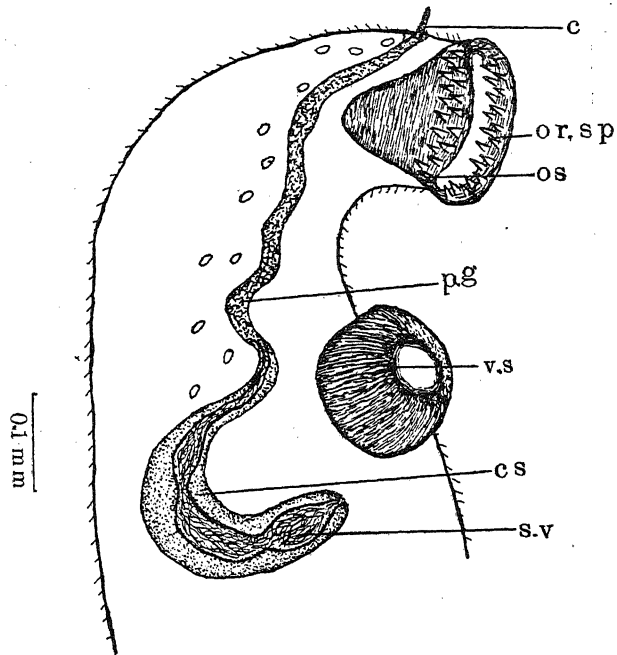


FIG 5.—*Masenia collata*, n. gen.. n. sp., anterior part of the
body showing cirrus sac.
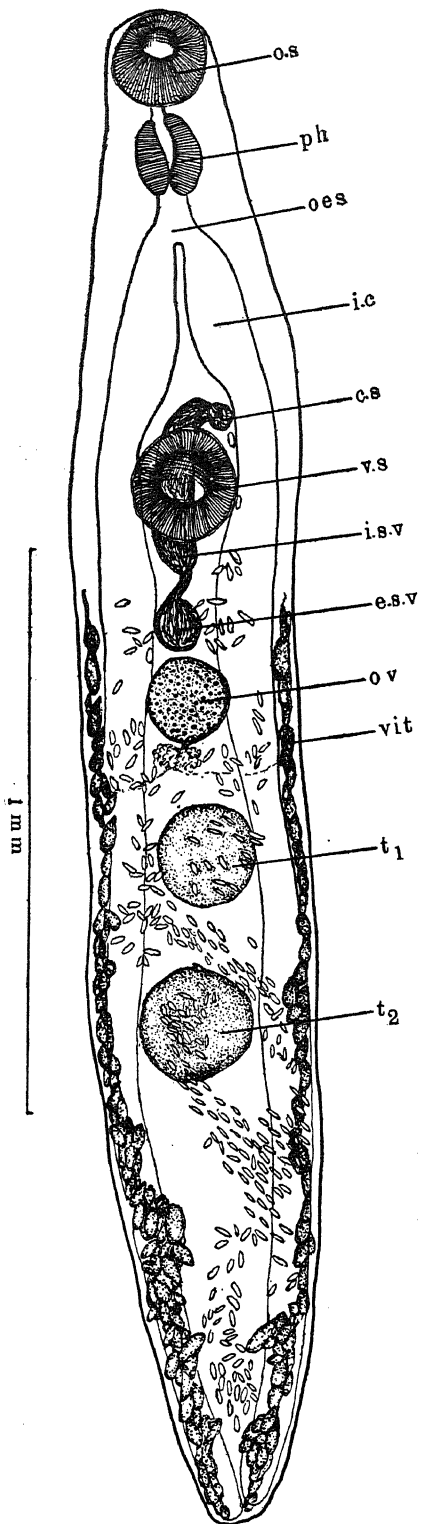
Fig 2.—*Ganada clariae*, n. gen., n. sp.,
ventral aspect.
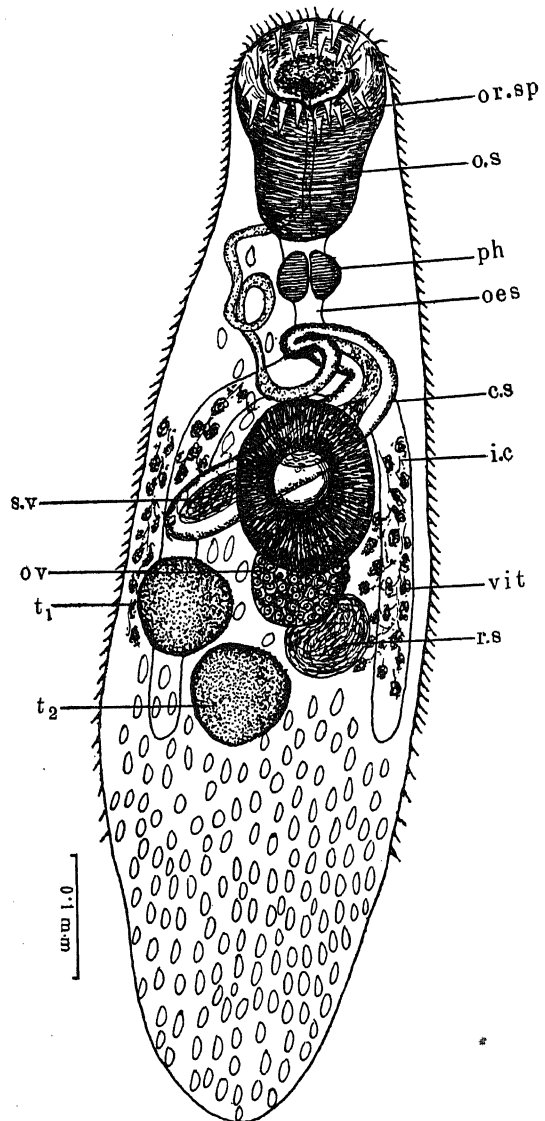
Fig 4.—*Masenia collata*, n. gen., n. sp., ventral
aspect.

# ON NEW TREMATODES OF FROGS AND FISHES OF THE UNITED PROVINCES, INDIA.

**Part I.**—New Distomes of the family Hemiuridæ Luhe 1901 from North Indian fishes and frogs with a systematic discussion on the family Halipegidæ Poche 1925 and the genera Vitellotrema Guberlet 1928 and Genarchopsis Ozaki 1925.

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## Introduction

In this paper are described a number of new distomes obtained from the gut of the frogs and fishes of Sitapur, Lucknow and Allahabad. Besides these forms a large number of other new species were obtained, which I shall describe in subsequent papers. The account of all these trematodes forms the subject of a thesis which I submitted in March 1933 in partial fulfilment of the requirements for the degree of Master of Science of the Allahabad University, and which for the purpose of publication I have split up into four parts. The first part as contained in this paper deals with two new species and a new variety of the genus *Halipegus* Looss 1899, two new species of the genus *Progonus* Looss 1899 and two new species of the new genus *Ophiocorchis*.

The systematic position of the family *Halipegidae* Poche 1925 and subfamily *Derogenetinae* Odhner 1927 of the family *Hemiuridae* Luhe 1901 is fully discussed and the author comes to the conclusion that the family *Halipegidae* is untenable and that the genus *Halipegus* should be included in the subfamily *Derogenetinae* of the family *Hemiuridae*. The synonymy of the genera *Vitellotrema* Guberlet 1928 and *Halipegus* Looss 1899 is clearly indicated. In the light of the new forms belonging to the genus *Progonus* which are decribed in this paper the genus *Genarchopsis* Ozaki 1925 is dropped and the species belonging to it is referred to the genus *Progonus*.

## Genus Halipegus Looss 1899

Vulpian in 1860 described *Distomum ovocaudatum*, parasitic in the mouth cavity and pharynx of European frogs. In 1872 Grebnitzky published an account of a new species of Distomum *Dist. kessleri* from the stomach of *Rana esculenta*. His paper was published in a rather obscure journal and therefore the parasite remained unknown till recently (1929). In 1890 Creutzburg worked the life history of *Dist. ovocaudatum*. This distome was also described independently by Sonsino and Looss in 1894. Five years later Looss created the genus *Halipegus* for *Dist. ovocaudatum*, assigning it somewhere near the *Syncoeliinae*. In 1905 Stafford recognized *Dist. ovocaudatum* Nickerson 1898, parasitic in *Rana catasbiana* and *R. clamata* to be a new species which he called *Halipegus occidualis*. Ssinitzin who in 1905 worked out the life cycle of *Cercaria cystophora* described by Wagener in 1866 from *Planorbis marginata* found that the cyst passes into a dragon-fly larva—*Colopteryx virgo*, which serves as its intermediate host and the frogs feeding on these larvæ become infected with *H. ovocaudatum*. Poche in 1925 created a new family *Halipegidae* for the genus *Halipegus* and placed it under his superfamily *Hemiuroidea* Poche 1925. As will be seen from the systematic discussion the family *Halipegidae* is untenable. Guberlet in 1928 added a new genus *Vitellotrema* from the stomach of a water snake to the family *Halipegidae* Poche. This genus which is based only on the unlobed character of the vitellaria cannot be maintained and I accordingly assign it to the genus *Halipegus* Looss as *H. fusipora*. In the following year Isaitschikow described *H. rossicus* from the stomach of a Russian frog—*R. esculenta* and Bychowsky referred *Dist. kessleri* Grebnitzky to the genus *Halipegus*. Wlassenko in 1929 found specimens of *H. kessleri* in the stomach of *Natrix natrix* pointing out the close resemblance between them and *H. rossicus*. The latter form he regarded as synonymous with *H. kessleri*. Simer found in the intestine of *Polyoden spathula H. perplexus*. which he described in 1929. I add in this paper to the genus *Halipegus* two new species and a new variety from the stomach and intestine of Indian frogs.

## Halipegus mehransis n. sp.

(Fig. 1)

Host—*Rana cyanophlyctis*.
Habitat—Stomach.
Locality—Sitapur, Oudh (India).

This is the most common trematode infecting *R. cyanophlyctis* in Sitapur district from May to September. During this period the frogs were found to be invariably infected with this parasite. The average intensity of infection is about 4 although the number varies from 2—12 in a single host. The distomes live firmly attached to the wall of the stomach by means of their large

and powerful ventral sucker which, when in use, may be prominently pro-
truded from the body. The free anterior end may be extended for some
distance in a leech-like manner. The parasites have little power of adapt-
ibility to changed conditions of diet and temperature, for none could live for
more than 28 hours in nutritive solutions kept at the laboratory temperature
(*vide* Table I).

### Table I
#### Date 2nd—6th August, 1932. Laboratory Temp. 70—82·5° F.

| Nutritive solu-tions used. | Physiological salt solution 0·75% | Phys. salt sol. and yolk 1:2 | Phys. salt sol. and albumen 1:1 | Phys. salt sol. and yolk and albumen 1:2:2 | 5% sugar solution. |
|---|---|---|---|---|---|
| Number of para-sites kept ... | 5 | 5 | 5 | 5 | 5 |
| Maximum num-ber of hours they lived ... | 6 | 20 | 18 | 28 | 8½ |
| Number of para-sites lived for m a x i m u m period ... | 2 | 3 | 2 | 3 | 1 |

The parasites are light grey in colour and have enormous power of con-
traction and expansion. The thick and muscular body is spindle-shaped with
bluntly pointed ends and a nearly circular cross-section. The bodywall is
smooth and entirely devoid of spines. It may be thrown into circular folds
which are more prominent with increased degree of contraction. These folds
give the trematodes a ringed appearance in the living condition. The sexual-
ly mature worms when alive vary from 1·7—4·5 mm in length and 0·6 – 0·9 mm
in breadth. In entire mounts the parasites measure 3·1—5·1 mm in length and
0·9—1·2 mm in maximum breadth which lies about the region of the acetabulum.

The suckers are well developed and highly muscular and have a circular
outline. The subterminal and ventrally directed oral sucker of 0·28 mm dia-
meter is nearly half the size of the acetabulum. The acetabulum of 0·5—0·72 mm
diameter and 1·8 times the size of the oral sucker, situated in the middle
of the body, is very deep extending nearly to the dorsal surface of the body.

The genital pore is ventral, usually median, rarely shifted slightly to one
side, a little behind the intestinal bifurcation. The excretory pore lies
terminally at the extreme hinder end of the body.

The pharynx, 0·1—0·14 mm in diameter, is situated just posterior and
slightly dorsal to the oral sucker. The oesophagus being absent the intesti-
nal caeca arise directly behind the pharynx. The caeca are broad and wavy
with several marked constrictions and extend up to the extreme posterior end.

The massive testes are extracaecal and have roughly triangular outline. They are situated obliquely, one on each side, close behind the anterior half of the body. The right testis, 0'3 – 0'6 × 0'27—0'43 mm in size, lies in the space between the right intestinal caecum and the bodywall, with its major portion in level with the posterior third part of the acetabulum. The left testis of 0'3—0'6 × 0'28—0'4 mm size is situated 0'09—0'17 mm behind the acetabulum in the space between the left intestinal caecum and the bodywall. The vesicula seminalis is a flask-shaped structure of 0'22—0'25 × 0'12 – 0'14 mm size, situated slightly to the right of the median line, a little behind the intestinal bifurcation. The vesicula seminalis narrows anteriorly to form the ductus ejaculatorius, 0'08 × 0'01 mm size, which bends downwards on the left side of the vesicula seminalis to open on a nipple-shaped cone or papilla lying in the genital atrium. The ductus ejaculatorius is surrounded by prostate gland cells which lie free in the parenchyma.

The ovary is nearly spherical in shape with entire margin, measuring 0'16—0'27 × 0'2– 0'3 mm in size. It is intracaecal lying just in front of the left vitelline gland close to the median line. The oviduct arising from the middle of the posterior margin of the ovary turns towards the median line and after running for a short distance is joined first by the Laurer's canal and soon after by the common vitelline duct, before it enters the compact shell gland mass of an oblong form and 0'17 – 0'2'5 × 0'11 – 0'17 mm size, situated obliquely to the right side in level with the ovary. The shell gland mass is separated from the latter by the anteriorly passing Laurer's canal. The Laurer's canal of 0'03 mm diameter has a number of transverse constrictions at regular intervals, throughout its length. A receptaculum seminis is absent. The relations of the female ducts are shown in figure 8.

The vitellaria lie in two groups, ventral to the intestinal caeca, one on either side of the median line close behind the ovary and the shell gland mass, ending posteriorly a little in front of the blind extremities of the intestinal caeca. The right vitelline gland, 0'3—0'46 × 0'2 mm in size, consists of four well marked lobes while the left one, 0'27—0'35 × 0'18—0'2 mm in size, has five lobes. The vitelline duct of each side runs measially and the two ducts meet in the median line to form the common vitelline duct just behind the shell gland mass.

The initial part of the uterus is filled with a huge number of sperms and hence may be regarded as receptaculum seminis uterinum. The uterus forms closely packed and irregularly arranged transverse convolutions which extend laterally up to the bodywall both in front and behind the acetabulum. The uterine coils, however, never extend behind the shell gland mass and the vitellaria. In its terminal part the uterus lies parallel to the vesicula seminalis and like the ductus ejaculatorius is lined internally with cuticle. The uterus opens on the genital papilla very close to the male opening. It contains numerous eggs of golden yellow colour which bear a very long filament

at one end. The egg measures 0˙045 × 0˙018 mm in size and filament 0˙32 mm in length. The filament is 7 or 8 times the length of the egg.

The excretory bladder is Y-shaped, consisting of an unpaired excretory vesicle extending from the posterior end right up to the level of the testes where it divides into two lateral cornua. The cornua extend anteriorly, one on either side, uniting with each other on the dorsal side of the pharynx.

This species bears a very close resemblance to *H occidualis* Stafford in the position of suckers, the extent of the intestinal caeca, lobed nature of the vitellaria, position of the gonads and the excretory pore. The important differences which mark it out as a new species are: the absence of the oesophagus, position of vitellaria and the genital pore, the union of the cornua of the excretory bladder in the region of the pharynx and not above the oral sucker, the size of the ova and the length of their filaments which are 7 or 8 times as long as the ovum and not shorter than the latter as in *H. occidualis*.

### Halipegus mehransis var. minutum n. var.
(Fig. 2)

Host—*Rana tigrina*.

Habitat—Stomach.

Locality—Sitapur, Oudh (India).

Eight specimens of this parasite were obtained from the stomach of two out of about sixty frogs examined during the rainy season in 1932. The distomes have a muscular and cylindrical body with marked power of contraction and expansion. In the living condition the parasites measure 0˙9—1˙9 mm in length and 0˙36—0˙7 mm in maximum breadth. Sexually mature worms in entire mounts measure 1˙6—1˙9 mm in length and 0˙6—0˙7 mm in maximum breadth across the testicular region.

The subterminal and ventrally directed oral sucker is transversely oval in outline, measuring 0˙14—0˙2 × 0˙19—0˙27 mm in size. The acetabulum, situated about the end of the anterior half of the body, is spherical in outline with a diameter of 0˙3—0˙4 mm. It is one and a half times as large as the oral sucker. The pharynx is spherical with a diameter of 0˙08—0˙1 mm and opens directly into the two broad and wavy intestinal caeca which extend up to the extreme posterior end of the body.

The topography of the gonads and the structure of the copulatory apparatus are very much similar to those of *H. mehransis* n. sp. The testes, ovary, vitellaria and the shell gland complex all occupy the same relative positions as in the above species. The testes are extracaecal, lying somewhat asymmetrically one on each side, close behind on the sids of the acetabulum. The left testis, 0˙16 - 0˙26 × 0˙11 - 0˙17 mm in size, lies a little cephalad of the right testis which measures 0˙12—0˙25 × 0˙11—0˙19 mm in size The vesicula seminalis of 0˙14—0˙17 × 0˙08—0˙096 mm size is situated slightly to the right of the median line close behind the intestinal bifurcation. The

short ductus ejaculatorius of about 0'075 mm length is surrounded by a few prostate gland cells. The male pore lies on a small conical papilla situated in the genital atrium.

The ovary is a small spherical structure of $0'10-0'11 \times 0'1-0'14$ mm size, situated close to the right side of the median line just in front of the right vitelline gland. The shell gland complex, $0'096-0'14 \times 0'06-0'08$ mm in size, lies obliquely behind the ovary on the side opposite to that of the ovary just in front of the left vitelline gland. A conspicuous Laurer's canal is present but the receptaculum seminis is absent.

The vitellaria lie in two somewhat obliquely situated groups, one on each side, close behind the ovary and the shell gland complex. The right vitelline gland of $0'14-0'22 \times 0'096-0'19$ mm size has five distinct lobes, while the left gland, $0'16-0'22 \times 0'06-0'14$ mm size, has only four such lobes. The vitelline ducts of both sides unite to form a common duct in the median line just behind the ootype.

The first crop of eggs produced are abortive. Two specimens of 1'6 mm length had the earliest eggs still in the uterine convolutions in the post-acetabular region. The most anterior eggs were about half the normal size and had irregular shape with very thin shell. The contents of the eggs were vacuolar in appearance. Fully mature specimens, however, have numerous golden yellow eggs in the transversely arranged coils of their uterus. The uterine convolutions are confined to the intercaecal area and never extend posterior to the ovary and the shell gland complex. Terminally the uterus opens on the genital papilla independently of the male opening. The eggs of $0'042-0'047 \times 0'02$ mm size have at one end a very long filament of $0'17-0'2$ mm length. The excretory system is as in *H. mehransis*.

This trematode shows very close resemblance to *H. mehransis* in the general form, shape and the topography of the various organs, but differs from it in the smaller size of the body and of the various organs, transversely oval shape of the oral sucker, position and size ratio of the acetabulum and the size of the egg and its filament and the host. On the basis of these differences I consider this parasite to belong to a new variety of *H. mehransis* which I name *var minutum* on account of its much smaller size.

### Halipegus spindale n. sp.

(Fig. 3)

Host— *Rana cyanophlyctis.*

Habitat—Intestine.

Locality—Sitapur, Oudh (India).

Four mature specimens of this parasite were obtained from the intestine of a frog examined in July 1932 at Sitapur. The parasites have a smooth and spindle-shaped body nearly circular in cross-section. The specimens fixed

under a slight pressure measure 3·1—3·4 mm in length and 0·86—0·96 mm in greatest breadth which lies across the acetabular region. The genital atrium is situated a little behind the intestinal bifurcation slightly to the left of the median line. The excretory pore lies subterminally on the ventral surface near the hinder end of the body.

The suckers are well developed, muscular and have a circular outline. The oral sucker, of 0·26 mm diameter, is situated subterminally on the v. ntral surface. The acetabulum, 0·52 mm in diameter, is situated in the region between the anterior third and the first half of the body. The acetabulum is twice as large as the oral sucker.

The oral sucker leads posteriorly into a thick-walled spherical pharynx of 0·1—0·11 mm diameter which is followed by a very short oesophagus of 0·05—0·08 mm length. The intestinal caeca, with markedly crenated outline, are of uniform breadth, extending more or less in a straight course up to the anterior end of the vitellaria.

The testes are more or less ovoid in shape and lie asymmetrically out-side the intestinal caeca, close behind the acetabulum. The left testis, 0·38—0·41 × 0·27—0·32 mm in size, is more cephalad, lying in part to the side of the acetabulum, while the right testis, 0·38—0·4 mm in size, is situated more caudad at about 0·17—0·2 mm distance behind the acetabulum. The vesicula seminalis of 0·21—0·22 × 0·1—0·12 mm size is a prominent bulb-shaped structure situated behind the intestinal bifurcation a little to the left of the median line. It is continued into a short bent ductus ejaculatorius of 0·13 mm length which opens on a short conical genital papilla situated in the shallow genital atrium. A number of prostate gland cells lie all round the ductus ejaculatorius.

The ovary, 0·16—0·17 × 0·19—0·22 mm in size, is intracaecal, situated to the right side in front of the right vitelline gland. The shell gland mass is an oval structure of 0·12 × 0·16 mm size, lying either in the median line or slightly to the left side close in front of the vitelline gland of the same side. The relations of the female genital ducts are as in *H. mehransis*.

The vitellaria lie in two groups, one on either side, at the extreme hinder end of the body and immediately behind the blind extremities of the intestinal caeca. The right vitelline gland of 0·3—0·32 × 0·24 mm size consists of five lobes while the left one measuring 0·3—0·32 × 0·16 mm in size has only four such lobes.

The uterus which is enormously developed and stuffed with numerous golden yellow eggs lies mostly in transverse convolutions extending up to the bodywall on either side. Terminally it opens on the small genital papilla situated in the shallow genital atrium. The eggs measure 0·045—0·047 × 0·02—0·022 mm in size and bear 'at their posterior end a long filament of 0·27 mm length.

The excretory system is as in *H. mehransis* with the difference that in this form the excretory pore lies subterminally on the ventral surface.

Of all the species of the genus *Halipegus spindale* bears a close relationship to *H. mehransis* in the form of the body, position of gonads and vitellaria, the relations of the female genital ducts and in the structure of the end apparatus of the reproductive organs. It differs, however, in the following important features which mark it out as a new species: the position and size ratio of the suckers, the presence of an oesophagus, the more or less straight and uniform breadth of the intestinal caeca ending in front of the vitellaria and the subterminal position of the excretory opening.

## Systematic discussion on the genus Halipegus Looss 1899 with remarks on the family Halipegidae Poche 1925, and the genus Vitellotrema Guberlet 1928.

The systematic position of the genus *Halipegus* has been much debated upon by various workers. Looss, who created the genus in 1899, assigned it a place near the *Syncoeliinae*. Luhe in 1901 included it in the family *Hemiuridae*. Ward and Whipple in 1918 and Nicoll in 1926 placed it in the category of unclassified genera. Dollfus in 1923 and Viana in 1924 assigned it to the *Syncoeliinae*. In 1925 Poche, however, created for it a new family *Halipegidae* which he included in his superfamily *Hemiuroidea*. Guberlet in 1928 and Faust 1930 following Poche have maintained the family *Halipegidae*. Odhner in 1927 created a new subfamily *Derogenetinae* under the family *Hemiuridae*, for the genera *Halipegus, Derogenes, Gonocerca* and *Lecithophyllum* which he considered to be closely related. Fuhrmann in 1928 follows Odhner in assigning the genus *Halipegus* to the *Derogenetinae*.

The genera *Halipegus* and *Derogenes* are closely related on account of the marked similarity in the general body-form, position and size of suckers, length of the intestinal caeca, topography of the gonads and the vitellaria, position of genital pore, large size of eggs with a polar filament at the posterior end and in the excretory system. The only points of difference between the two genera are in the position and arrangement of uterine coils and the extent of the prostate glands—characters which can at the most be considered of generic importance. I, therefore, drop the family *Halipegidae* Poche 1925 and include the genus *Halipegus* in the *Derogenetinae*.

The genus *Vitellotrema* as included in the family *Halipegidae* by Guberlet differs from the type genus of the family only in the unlobed character of the vitelline glands. There is one species of *Halipegus*, *i.e.*, *H. kessleri* syn. *H. rossicus* which has got unlobed vitelline glands like those of the genus *Vitellotrema*. It seems that Guberlet was not aware of the latter condition, as appears from the list of references given in his paper, otherwise he would not have thought of creating his new genus on the basis of this character.

The lobed or unlobed character of the vitelline glands, as discussed by Looss in 1901 and Manter in 1926, should not be considered to be of generic importance even in cases where the lobes are distinctly separated into closely aggregated follicles. This view is also supported by the condition of the vitelline glands in the new species of Progonus Looss and of *Ophiocorchis* n. gen. which are described by me in this paper. These species resemble each other closely in most features except in the lobed or unlobed character of the vitellaria. I, accordingly, drop the genus *Vitellotrema* and refer its type species to the genus *Halipegus*.

The diagnosis of the genus *Halipegus* as now constituted is as follows :--

*Derogenetinae:* with a highly muscular and smooth, usually cylindrical rarely flattened body. The suckers are well developed and muscular; the acetabulum larger than the oral sucker, situated about or in the middle of the body. Muscular pharynx present; oesophagus present or absent, intestinal caeca long extending either up to the extreme hinder end or stopping in front of the vitelline glands. The excretory bladder is Y-shaped with a long median stem and two long cornua which run forwards and unite together in the region of the oral sucker or the pharynx. The genital pore is situated either in the region of the pharynx or distinctly behind the intestinal bifurcation ; a small genital atrium is present. A ductus hermaphroditicus may be absent or present. The testes two in number, situated symmetrically or asymmetrically in the first half of the post-acetabular region ; a small vesicula seminalis and a slight pars prostatica are present but a cirrus is absent. The rounded ovary is situated near the hinder end of the body in front of the vitellaria. The vitellaria lie in two lobed or unlobed groups placed symmetrically or obliquely behind the ovary at the hinder end of the body. Receptaculum seminis is absent. Laurer's canal is present. The long uterus consists of only ascending part in transverse coils containing a huge number of large-sized eggs bearing a long or short polar filament at their posterior end. Parasitic in the mouth cavity, eustachian tubes, pharynx, stomach and intestine of fishes, frogs and snakes.

### Key to the species of the genus Halipegus Looss.

Vitelline glands lobed                  A

Vitelline glands unlobed            B

A.   Testes situated far behind the acetabulum, close to

     the ovary    .    .   .   .   .   .   .   *H. ovocaudatum*

     Testes situated close behind the acetabulum, far

     in front of the ovary    .   .   .   .   .   .   1

    1.   Oesophagus present                2

       Oesophagus absent               3

F. 7

2. Intestinal caeca extend up to the extreme posterior
   end and the excretory pore terminal    .  .  .  *H. occidualis*

   Intestinal caeca end in front of the vitellaria,
   excretory pore subterminal    .    .    .    .  *H. spindale* n. sp.

3. Genital pore lies in the region of the pharynx,
   the uterine coils do not overlap the intestinal
   caeca anteriorly in front of the testes    .    .  *H. longispina*

   Genital pore situated behind the intestinal bifurca-
   tion; uterine convolutions extend to the body-
   wall both in front and behind the acetabulum    .  4

4. Size 3·1—5·1 mm; acetabulum situated in the
   middle of the body 1·8 times the size of the
   oral sucker    .    .    .    .    .    .    .    .  *H. mehransis* n. sp.

   Size 1·9—1·9 mm; acetabulum situated between
   first 1/3 and 1/2 of the body and twice the size of
   the oral sucker    .    .    .    .    .    .    .  *H. mehransis var*
                                                        *minutum* n. var.

B. Intestinal caeca reach behind the vitellaria up to
   the extreme hinder end of the body    .    .    .  *H. fusipora.*

   Intestinal caeca stop in front of the vitellaria    .    .  *H. kessleri.*

### Genus *Progonus* Looss 1899 (= Genarches)

The only hitherto known species of this genus was described by Levinsen
in 1881, for which Looss in 1899 created the genus *Progonus*, assigning it to
the *Syncoeliinae* Looss. Luhe founded the family *Hemiuridae* in 1901 and
included in it the genus *Derogenes* along with the genera with tail appendage.
Looss in 1907 limited the scope of the family and retained under it only such
forms as possess a tail appendage. Odhner in 1911 pointed out that *Derogenes*
is so closely related to the other *Hemiuridae* that its separation from the
family is impossible and that the genus *Progonus* which is closely related to
*Derogenes* should be included in the *Hemiuridae*. Nicoll in 1913 agreed with
Odhner in this view reducing the family *Hemiuridae* Looss to the position
of a subfamily. Ozaki in 1925 described a new genus *Genarchopsis* a form
closely resembling *Genarches mulleri* (Levins) and assigned it to the subfamily
*Syncoeliinae*. Odhner in 1927 pointed out that *Progonus* shows a close rela-
tionship with *Derogenes* in most of its characters and consequently he included
it with *Derogenes* in a new subfamily *Derogenetinae*. The only feature in
which *Progonus* differs from *Derogenes* is the presence of a caudal anastomosis
of the intestinal caeca near the hinder end of the body, which Odhner con-
siders to be an example of "convergence". In the following year Fuhrmann
following Odhner included the genera *Derogenes, Genarchopsis, Gonocerca,
Licithophyllum, Bunocotyle,* and *Halipegus* in the subfamily *Derogenetinae*.

The systematic discussion at the end of the description of the new species of
*Progonus* in this paper will show that the genus *Genarchopsis* Ozaki 1925 is
identical with *Progonus* and that *P. ovocaudatum* is an intermediate species
between the two synonymous genera.

## Progonus piscicola n. sp.

(Fig 4)

Host—*Ophiocephalus punctatus*.
Habitat— Stomach.
Locality—Allahabad.

Three specimens of this trematode were obtained from the stomach of
one out of about a dozen fish examined in June 1932. In the living condition
the parasites are light brown in colour and show great power of contraction
and expansion. The body is muscular and somewhat cylindrical in form
with a broadly rounded off anterior and a pointed posterior end. The distomes
are of moderate size measuring 3·3—3·4 mm in size and 1·12 in maximum
breadth which is attained about the middle of the body. The body in
front of the acetabulum is uniformly broad while the post-acetabular portion
tapers sharply to the posterior pointed end. The well-developed and muscular
suckers have a circular outline. The oral sucker measuring 0·33—0·34 mm in
diameter lies subterminally at the anterior end of the body, with its cavity
directed towards the ventral surface. The acetabulum of 0·66—0·68 mm
diameter is twice as large as the oral sucker, situated in the first half of the
post-equatorial region.

The oral sucker opens posteriorly into a spherical thick-walled pharynx
of 0·12—0·14 mm diameter. In the absence of an oesophagus the intestinal
bifurcation takes place directly behind the pharynx at a distance of
0·48—0·53 mm from the anterior end. The intestinal caeca have a highly
crenated outline and run at first transversely and then turning downwards
continue in a wavy course up to the hinder end of the body where they are
continuous into each other just in front of the vitellaria.

The excretory bladder is Y-shaped consisting of an unbranched median
stem which bifurcates just behind the acetabulum into two long cornua
extending laterally right up to the level of the pharynx and uniting with
each other on the dorsal side of the latter. The excretory bladder opens ter-
minally at the hinder end of the body. The terminal part of the bladder is
surrounded by a sphincter formed by a group of deeply staining parenchy-
matous cells with prominent nuclei.

The semilunar slit-like genital pore is sinistral or median, situated
ventrally in level with the pharynx. It leads into a roomy genital atrium of

0·13—0·15 mm depth within which projects a highly contractile nipple-shaped genital cone or papilla. Both the genital atrium and the papilla are lined with cuticle. On the tip of the genital papilla opens the short common genital duct which may be termed as the ductus hermaphroditicus.

The testes are extracaecal and ovoid in form, situated a little obliquely behind the acetabulum, one on each side between the intestinal caeca and the bodywall. The left testis, 0·16—0·22 × 0·17 mm in size, lies slightly nearer the acetabulum than the right testis which measures 0·17—0·19 × 0·16—0·22 mm in size. The vesicula seminalis consists of an elongated coiled tube filled with sperms lying free in the parenchyma. Anteriorly it is continued into a short ductus ejaculatorius which opens in the terminal part of the uterus forming a short ductus hermaphroditicus. A few prostate gland cells surround the ductus ejaculatorius.

The ovary is an oval structure of 0·14—0·2 × 0·17—0·19 mm size, situated intracaecally to the right of the median line close behind the right testis. The shell gland complex, measuring 0·14—0·19 × 0·16—0·17 mm in size, is a prominent compact structure lying in contact with the posterior margin of the ovary. The vitellaria consists of two large compact glands situated asymmetrically in the extreme hinder part of the body behind the intestinal arc. The right vitelline gland 0·16—0·17 × 0·16 mm in size, lies obliquely behind the left gland of 0·2—0·25 × 0·15 mm size. The vitelline ducts of each side join together to form a short common duct which opens into the oviduct. A Laurer's canal is present but a receptaculum seminis is absent. The relations of the female genital ducts are shown in figure 9. The uterus lies in thickly crowded ascending coils which extend on the sides up to the bodywall. The initial part of the uterus is filled with sperms and may be regarded as the receptaculum seminis uterinum. Posteriorly the uterine convolutions do not extend beyond the shell gland complex. The terminal part of the uterus receives the ductus ejaculatorius forming a short ductus hermaphroditicus which opens on the genital papilla. A metraterm is absent. The numerous golden yellow eggs are fairly large measuring 0·048 × 0·015 mm in size and bearing a polar filament of 0·04 mm length at its posterior end.

In its affinities *Progonus piscicola* n. sp. stands nearest to *P. goppo* owing to the close similarity in the general shape of body with smooth cuticle, the size of the acetabulum, absence of a prepharynx and oesophagus, oblique position of the testes, compact nature of the two vitelline glands, absence of a receptaculum seminis and the uterine convolutions being confined anterior to the vitellaria. The important points of differences are: the larger size of body, distinctly caudad position of the acetabulum, size ratio of the suckers, position of the genital pore, topography of the gonads, asymmetrical position of the vitellaria, the arrangement and extent of the uterine coils which extend up to the bodywall on either side.

## Progonus ovocaudatum n. sp.

(Fig. 5)

Host—*Ophiocephalus punctatus*.

Habitat—Intestine.

Locality—Allahabad.

Only two specimens of this species were obtained from the intestine of one out of about thirty fish examined by me in the winter months of 1932. The parasites have a smooth and muscular body, somewhat cylindrical in form with broadly rounded off ends. They may at times present a slightly ringed appearance in the contracted condition. In entire mounts the distomes measure 1·5—2·3 mm in length and 0·5—0·8 mm in maximum breadth which occurs in the preacetabular region. The suckers are well developed, spherical and muscular. The subterminal and ventrally directed oral sucker measuring 0·048—0·064 mm in diameter is half the size of the ventral sucker which measures 0·096—0·12 mm in diameter. The ventral sucker is situated in the middle of the body with its major portion lying caudad of the body centre. The genital pore lies near the median line just behind the intestinal bifurcation. The genital atrium is about 0·07 mm deep and encloses a small contractile papilla. The excretory system is as in other species of the genus.

The mouth leads posteriorly into a muscular pharynx of 0·01 mm diameter. An oesophagus is absent. The intestinal caeca have a broad and wavy outline with marked constrictions along its course and are continuous at the posterior end in front of the vitellaria.

The testes are somewhat triangular in outline, lying a little asymmetrically, one on either side about the middle of the post-acetabular region. The left testis, measuring 0·1—0·16 × 0·13—0·17 mm in size, is slightly larger than the right one which is 0·14—0·16 × 0·13—0·19 mm in size. The vesicular seminalis is a curved tube of 0·4 × 0·05 mm size lying in two turns to the right side of the median line. It opens into the terminal part of the uterus through a small ductus ejaculatorius which is surrounded by prostate gland cells.

The ovary lies close behind the left testis. It is a spherical structure of 0·1—0·17 mm diameter. The shell gland complex, 0·05 mm in diameter, is situated in the median line behind the ovary just in front of the intestinal arc. A Laurer's canal is present but a receptaculum seminis is absent.

The uterus is well developed and lies in transverse convolutions which extend at a few places beyond the intestinal caeca on either side. Posteriorly the uterine coils extend between the vitelline glands up to the hinder end of the body. The terminal part of the uterus is as in *P. piscicola*. The uterus is packed with numerous small golden yellow eggs of 0·037 × 0·017 mm size, bearing a small polar filament at its hinder end

The vitellaria consist of two compact, symmetrically situated glands, one on either side in the posterior end and behind the intestinal anastomosis. The

left vitelline gland measures 0'13—0'19 × 0'05—0'08 mm in size while the right one is of 0 08—0'17 × 0'09 – 0'1 size.

This interesting species resembles *P. piscicola* n. sp. in the general body-form and size ratio of the suckers, absence of prepharynx and oesophagus, the end apparatus of the reproductive system and the lateral extent of the uterine coils. It differs, however, from the above species in the smaller size of body, position of the acetabulum, the course of the intestinal caeca, more caudal position of the testes, smaller size and position of the shell gland mass, the symmetrical position of the vitellaria and in the important fact that the uterine convolutions extend posteriorly beyond the shell gland mass and lie in the space between the two compact vitelline glands at the extreme hinder end of the body. In this last character this species resembles *P. mulleri.* (Levins.)

### Systematic discussion on the genus Progonus Looss (=Genarches Lss.) and on the genus Genarchopsis Ozaki 1925

In discussing the diagnostic features of his new genus "*Genarchopsis*" Ozaki points out that his species bears a very close resemblance to *Genarches mulleri* (Levins) in the general shape of the body, the structure of the end apparatus of the reproductive organs and the excretory system but it differs in the convolutions of the uterus which do not stretch back further than the vitellaria. We find that *P. ovocaudatum* n. sp. resembles *Genarchopsis goppo* in nearly all features except in the extent of the uterus which extends further backwards than in the latter species, reaching up to the hinder end of the vitellaria or body. As the only distinction between the genera *Genarchopsis* and *Progonus, i.e.,* in the extent of the uterus ceases to exist in my species *P. ovocaudatum,* the identity of *Genarchopsis* with *Progonus* becomes quite clear. I maintain that these two genera are identical and synonymous. This view is also supported by the condition of the uterine coils in the two species of *Ophiocorchis* n. gen. described in subsequent pages.

I assign the genus *Progonus* to the subfamily *Derogenetinae* Odhner 1927. I agree with Odhner that the posterior anastomosis of the intestinal caeca in *Progonus* must not be given undue systematic importance. The posterior intestinal anastomosis is present in many distantly related forms such as *Cyclocoelium, Progonus, Opicoelous* and *Coitocoecum,* etc., and therefore must be considered as an example of convergence.

In view of what has been said above the diagnosis of the genus *Progonus* as given by Looss in 1899 needs a certain amount of modification. The amended diagnosis is as follows :—

Small distomes with elongated, flattened or cylindrical body tapering at both ends ; suckers strongly developed ; skin entire. Prepharynx present, oesophagus absent, intestinal caeca continuous into each other at the hinder

end of the body. Genital pore situated near the hinder end of the pharynx or behind the intestinal bifurcation; genital sinus is formed by the union of the male and female ducts and opens on a genital papilla; pars prostatica and the vesicula seminalis, however, not strikingly elongated and the latter does not reach the acetabulum towards its hinder end. Testes and ovary simple, rounded or oval. The vitellaria consist of two glands which may be lobed or compact, lying one on either side close behind the ovary. The uterine convolutions may or may not stretch back up to the hinder end of vitellaria. Excretory system as typical of the subfamily, i e., Y-shaped with the cornua uniting dorsal to the oral sucker or pharynx. Parasitic in the intestine and stomach of fresh-water and marine fishes.

## Key to the species of the Genus Progonus Looss 1899

    Uterus extends behind the shell gland mass  
      reaching up to the posterior part of vitellaria ... 1  
    Uterus does not extend posteriorly up to the  
      vitellaria ... ... ... ... 2  
1.  Genital pore situated at the hinder end of pharynx  P. mulleri.  
    Genital pore situated a little behind the intestinal  
      bifurcation ... ... ... ... P. ovocaudatum.  
2.  Uterine coils confined to intercaecal space ... P. goppo.  
    Uterine coils not confined to the intercaecal space  
      but extending to the bodywall on either side ... P. piscicola.

## Ophiocorchis lobatum. n. gen.; n. sp.

(Fig. 6)

Host—*Ophiocephalus striatus.*  
Habitat—Stomach.  
Locality—Lucknow.

    In September 1932 I examined about thirty living specimens of *O. striatus* received from Lucknow, only two of which were found infected with two specimens each of this parasite. The distomes have a highly muscular and cylindrical body with smooth cuticle. In permanent mounts they measure 2·8—3·2 mm in length and 1·1—1·2 mm in breadth across the acetabular region. The well-developed suckers have a spherical outline. The oral sucker, 0·3 mm in diameter, occupies a subterminal position on the ventral surface. The acetabulum, measuring 0·76 mm in diameter, is 2·5 times the size of the oral sucker and is situated about the middle of the body.

The genital pore lies close behind the intestinal bifurcation, slightly to the right of median line at a distance of 0˙44 mm from the anterior end. The excretory system is as in the genus *Progonus* Looss.

A prepharynx is absent. The mouth opens directly into a thick-walled spherical pharynx of 0˙12 − 0˙14 mm diameter. Though an oesophagus is absent a peculiar and highly contractile pouch is given off on the dorsal side from the junction of the pharynx with the intestinal bifurcation, and this I should consider to represent the oesophageal pouch. The food first directly passes from the pharynx into this pouch and when the latter contracts it is forced into the intestinal caeca. The oesophageal pouch always lies behind the intestinal bifurcation and is lined internally with cuticle measuring 0˙16 mm in length and 0˙08 mm in maximum breadth. Such a pouch is not known to be present in any of the trematodes so far known. The intestinal caeca are broad and wavy and unite with each other at the hinder end of the body, slightly in front of the vitellaria.

The testes are transversely oval in shape and lie asymmetrically one on either side close behind the acetabulum. The left testis, 0˙16 − 0˙2 × 0˙24 − 0˙32 mm in size, is situated nearer the acetabulum than the right testis which is 0˙16 − 0˙19 × 0˙25 − 0˙28 mm in size. The vesicula seminalis is a sac-shaped structure of 0˙3 − 0˙4 mm size and lies to the right of the median line close to the right intestinal caecum. Anteriorly it is continued into a short bent neck of 0˙07 × 0˙01 mm size which opens into an oval pars prostatica of 0˙08 − 0˙15 × 0˙05 − 0˙08 mm size. The pars prostatica opens directly into the terminal part of the metraterm. A large number of prostate gland cells lie all round the pars prostatica.

The ovary is an ovoid structure, 0˙17 − 0˙2 × 0˙2 − 0˙22 mm in size, situated to the right side about half way between the right testis and the right vitelline gland. The shell gland complex lies a little obliquely behind the ovary on the opposite side of the body. A Laurer's canal is present but a receptaculum seminis is absent.

The vitellaria consist of two-lobed glands lying one on either side behind and partly overlapping the caudal anastomosis of the intestinal caeca. Each gland is marked out into a varying number of lobes all of which are united in the centre. The right vitelline gland, 0˙22 − 0˙32 × 0˙19 − 0˙2 mm in size, consists of 5 − 7 lobes while the left one measuring 0˙22 − 0˙29 × 0˙14 − 0˙19 mm in size has 4 − 7 lobes.

The initial part of the uterus is filled with sperms forming a receptaculum seminis uterinum. The uterus is arranged in closely packed transverse convolutions which extend up to the bodywall on either side. Posteriorly the coils do not extend in the region of the vitellaria. The terminal part of the uterus passes into a well-developed and muscular metraterm which receives near its distal end the opening of the pars prostatica and then continues

onwards as the ductus hermaphroditicus which is protrusible. The eggs, measuring 0·045 × 0·02 mm in size, are of golden yellow colour and have a polar filament of 0·05—0·06 mm length at its posterior end.

## Ophiocorchis singularis n. sp.

### (Figs. 7 and 8.)

Host—*Ophiocephalus striatus.*

Habitat—Intestinal caeca.

Locality—Sitapur, Oudh.

Only one specimen of this parasite was obtained from the intestinal caeca of one out of about thirty fish examined at Sitapur in June 1932. The small distome has a smooth muscular body of a cylindrical form. In entire mounts it measures 1·96 mm in length and 0·72 mm in breadth across the acetabular region. The oral sucker of 0·22 mm diameter occupies a subterminal position on the ventral surface of the body. The acetabulum is of twice the size of the oral sucker and measures 0·46 mm in diameter. It is situated for the greater part of its length caudad from the middle of the body. The genital pore lies in the median line close behind the intestinal bifurcation at a distance of 0·35 mm from the anterior end.

A prepharynx is absent but a muscular pharynx of 0·12 mm diameter is present. From the junction of the pharynx and the intestinal bifurcation an oesophageal pouch of 0·13 × 0·05 mm size is given out. The intestinal caeca form a caudal anastomosis at the hinder end of the body in front of the vitelline glands.

The testes are oval in outline, situated asymmetrically one on each side behind the acetabulum. The left testis, 0·11—0·17 mm in size is situated a little in front of the right one, which measures 0·08—0·17 mm in size. The vesicula seminalis is a sac-shaped structure of 0·27—0·06 mm size. It discharges its contents through a 0·04 mm long duct into an oval pars prostatica of 0·08 × 0·06 mm size. The latter opens into the distal part of the muscular metraterm.

The nearly spherical ovary, 0·14—0·16 mm in size, is intracaecal, situated on the right side just in front of the intestinal anastomosis. The shell gland complex of 0·08 mm diameter lies in level with the ovary on the side opposite to it. A Laurer's canal is present but a receptaculum seminis is absent.

The vitellaria consist of two glands lying somewhat asymmetrically behind the intestinal anastomosis. The glands do not possess clearly marked off lobes but have a compact appearance. The left vitelline gland measuring 0·17 × 0·12 mm in size lies a little anterior of the right one which measures 0·19 × 0·096 mm in size.

The uterus lies in transverse convolutions which are confined to the intercaecal area. Posteriorly it extends between the two vitelline glands.

F. 8

Terminally the uterus passes into a well-developed muscular metraterm of
0·15 × 0·05 mm size which after receiving the pars prostatica is continued as
the ductus hermaphroditicus of 0·12 mm length. The ductus hermaphrodi-
ticus is capable of being protruded out of the 0·075 mm deep genital atrium
and functions as a copulatory organ. The eggs measure 0·035 × 0·017 mm
in size and bear a polar filament of 0·012 mm length at one end.

O. *singularis* n. sp. bears a very close resemblance to the type species
O. *lobatum* n. sp. The points of similarity are the presence of an oesophageal
pouch, a metraterm, a pars prostatica and the topography of the gonads.
It differs, however, from the latter species in the smaller size of the body, the
extent of its uterine coils, position and size of the acetabulum and the compact
nature of the vitelline glands.

I assign this new genus *Ophiocorchis* to the subfamily *Derogenetinae* of
the family *Hemiuridae*. Of all the genera of the subfamily this interesting
parasite in its affinities comes nearest to the genus *Progonus* Looss 1899 (as
already amended by me in this paper). It shows some resemblance with the
latter genus in the general body-form, position of the genitalia and the
arrangement of the uterine coils. The remarkable points of difference which
warrant the creation of a new genus for its reception are the presence of a
well-developed globular pars prostatica, a large and highly muscular metra-
term, a protrusible ductus hermaphroditicus capable of functioning as the
copulatory organ and the presence of a peculiar structure which I have termed
as the oesophageal pouch.

### Key to the species of the genus Ophiocorchis

1. Vitelline glands lobed and the uterine coils do not
   extend in the region of the vitellaria          ... O. *lobatum.*
2. Vitelline glands compact with the uterine coils
   extending between the two compact vitelline
   glands          ...          ...          ...          ... O. *singularis.*

### EXPLANATION OF THE PLATES

Fig. 1. Ventral view of Halipegus mehransis.
Fig. 2. Ventral view of H. mehransis var minutum.
Fig. 3. Ventral view of H. spindale.
Fig. 4. Ventral view of Progonus piscicola.
Fig. 5. Ventral view of P. ovocaudatum.
Fig. 6. Ventral view of Ophiocorchis lobatum.
Fig. 7. Ventral view of O. singularis.
Fig. 8. Diagrammatic view of female sexual organs of—H. mehransis.
Fig. 9. Diagrammatic view of female sexual organs of—P. piscicola.

## LETTERING

| | | | | | |
|---|---|---|---|---|---|
| Act. | ... | Acetabulum | Oot. | ... | Ootype |
| C | ... | Cirrus | Ph. | ... | Pharynx |
| C. s. | ... | Cirrus sac | P. ph | .... | Prepharynx |
| Eg. | ... | Egg | Pr. g. | ... | Prostate glands |
| D. ej | ... | Ductus ejaculatorius | P. p. | ... | Pars prostatica |
| D. h. | .. | Ductus hermaphroditicus | R. s. | ... | Receptaculum seminis |
| E. b. | ... | Excretory bladder | R. s u. | ... | Receptaculum seminis uterinum |
| E. p. | ... | Excretory pore | S. gl. | ... | Shell gland |
| G a. | ... | Genital atrium | S. gl. c. | ... | Shell gland complex |
| G. p. | ... | Genital pore | T. | ... | Testis |
| Int. c. | ... | Intestinal caecum | Ut. | ... | Uterus |
| L. c. | ... | Laurer's canal | V. d. | ... | Vas deferens |
| Mtm. | ... | Metraterm | Vit. | ... | Vitellaria |
| Oes. | .. | Oesophagus | V. sm. | ... | Vesicula seminalis |
| Oes. p. | ... | Oesophageal pouch | V. s. | ... | Ventral sucker |
| O. s | ... | Oral sucker | Y. d. | ... | Yolk duct |
| Ov. | ... | Ovary | Y. r. | ... | Yolk reservoir |
| O. d. | ... | Oviduct | | | |

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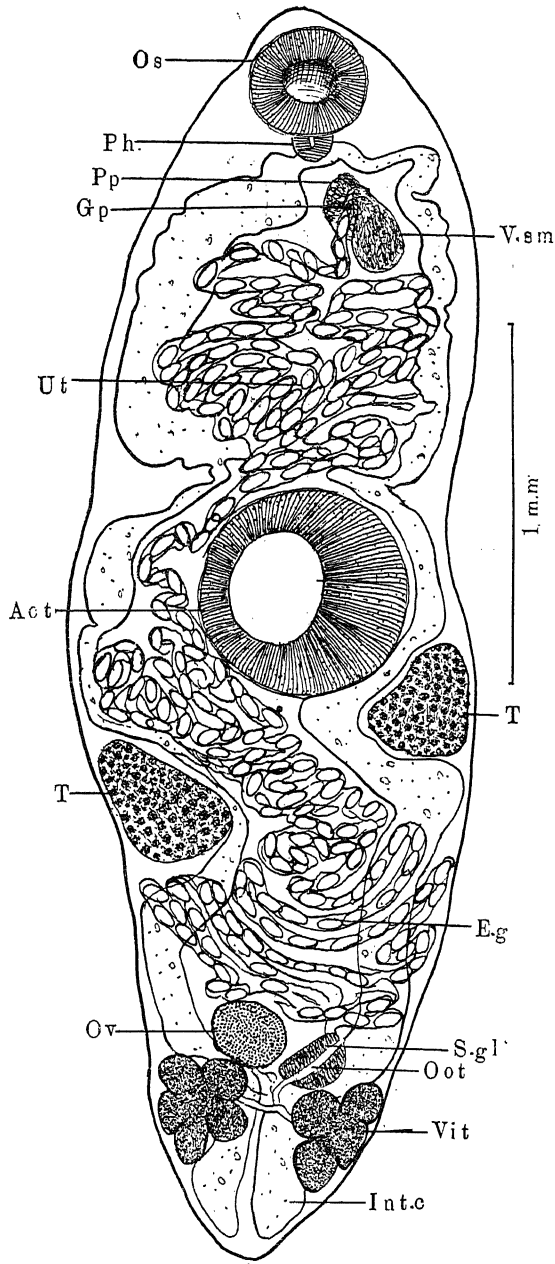
FIG. 1.—Halipegus mehransis, n. sp.
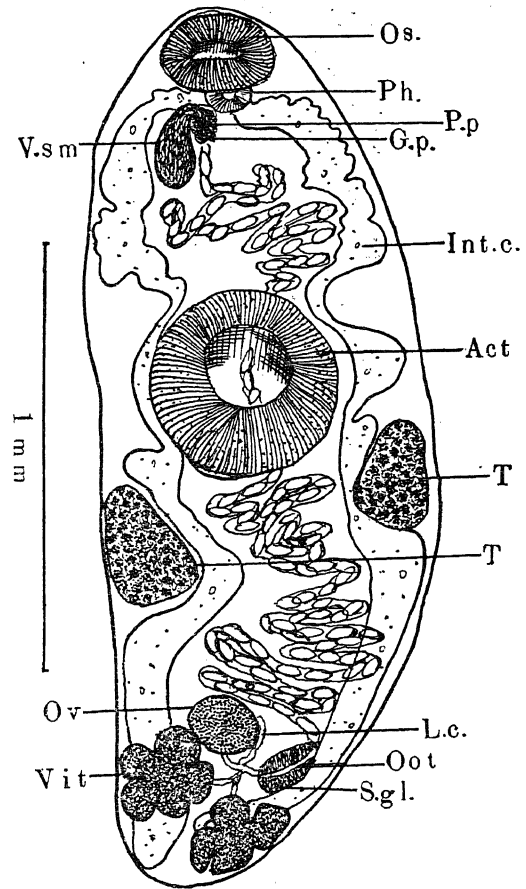
FIG. 2.—Halipegus mehransis, var minutum.
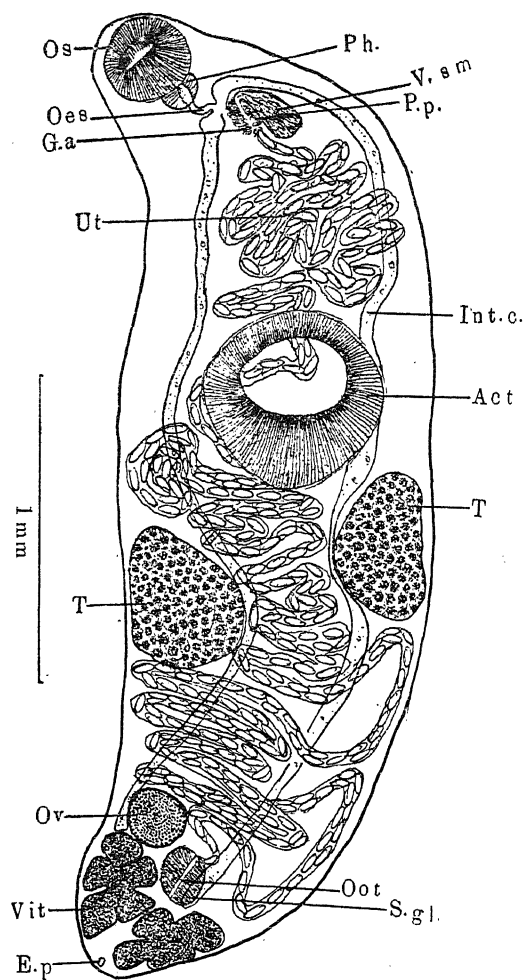
FIG. 3.—Halipegus spindale, n. sp.
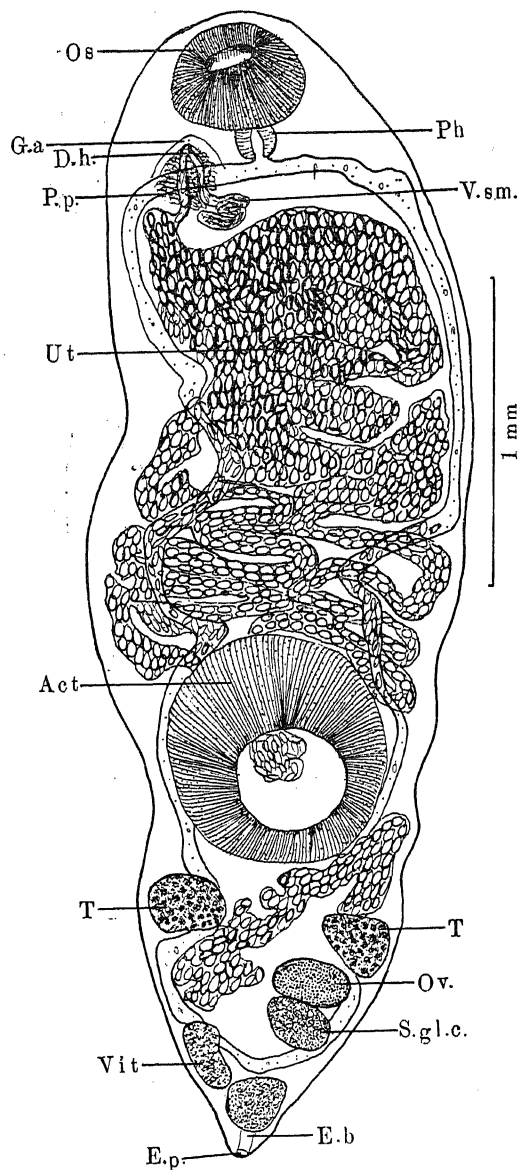


FIG. 4.—Progonus piscicola, n. sp.

FIG. 6.—Ophiocorchis lobatum, n. gen., n. sp.
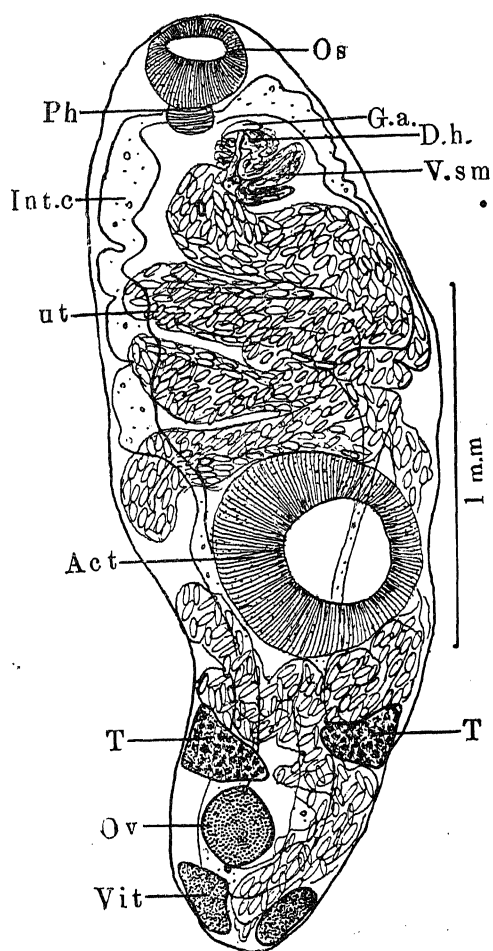
FIG. 5.—Progonus ovocaudatum
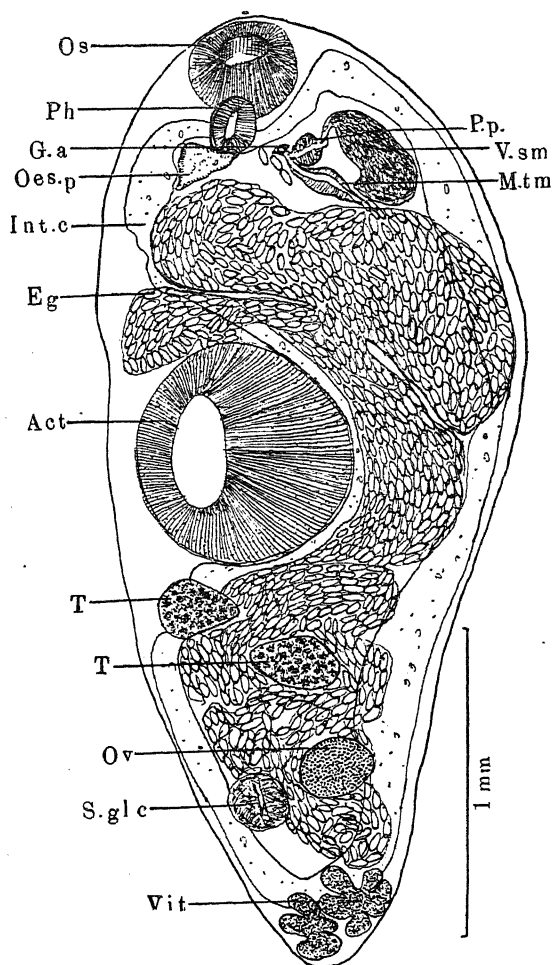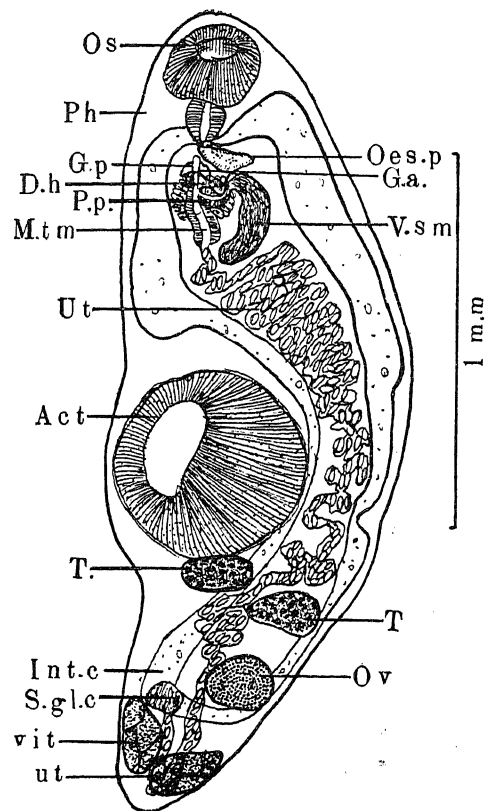
FIG. 7.—Ophiocorchis singularis
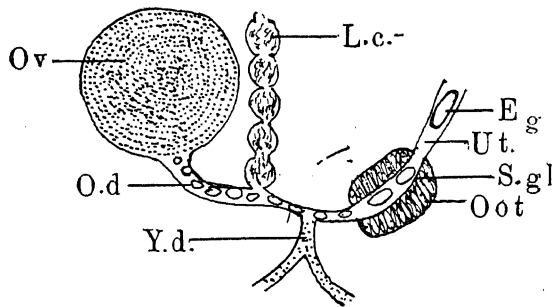
FIG. 8.
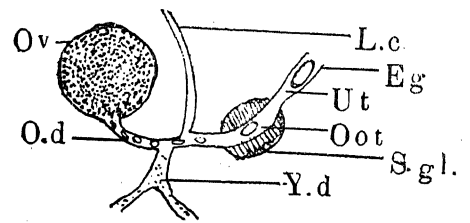
FIG. 9.

## ON SYNGE'S PAPER[1]

By S. Subramanian

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Synge has started with the metric

$$ds^2 = F(x^1, x^2,\ldots\ldots x^n \; ; \; dx_1, dx_2,\ldots\ldots dx^n) = F(x \; ; \; dx)$$

where $F$ is a homogeneous function of the second degree in $dx$, and has defined parallel transport along $x^i = x^i(s)$ $(i = 1, 2,\ldots\ldots n)$ by the equations

$$\dot{X}^i + \left\{ \overline{\frac{jk}{i}} \right\} X^j \ddot{x}^k + \left\{ \frac{jk}{i} \right\} X^j \dot{x}^k = 0 \qquad (i = 1, 2, \ldots n) \qquad \ldots \text{(I)}$$

where $X^i$ is a contravariant vector,

$$2\left[ \overline{\frac{jk}{i}} \right] = \frac{\delta f_{ij}}{\delta \dot{x}^k} + \frac{\delta f_{ik}}{\delta \dot{x}^j} - \frac{\delta f_{jk}}{\delta \dot{x}^i}, \qquad \ldots \qquad \ldots \qquad \ldots \text{ I(1)}$$

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$$\left\{ \overline{\begin{matrix} jk \\ i \end{matrix}} \right\} = f^{il} \left[ \overline{jk, l} \right],$$

$$2 \left[ \begin{matrix} jk \\ i \end{matrix} \right] = \frac{\delta f_{ij}}{\delta x^k} + \frac{\delta f_{ik}}{\delta x^j} - \frac{\delta f_{jk}}{\delta x^i}, \qquad \dots \qquad \dots \qquad \dots \quad \text{I(2)}$$

$$\left\{ \begin{matrix} jk \\ i \end{matrix} \right\} = f^{il} \left[ jk, l \right],$$

$$f_{ij} = \tfrac{1}{2} \frac{\delta^2}{\delta \dot{x}^i \delta \dot{x}^j} \mathrm{F}(x_j ; \dot{x}), \qquad \dots \qquad \dots \qquad \dots \quad \text{I(3)}$$

and $f_{ij} \, f^{kj} = \delta_i^k$ (it being assumed $| f_{ij} | \neq 0$).

But he has not proceeded to define parallelism in terms of covariant vectors.

Given a contravariant vector $\mathrm{X}^i$, we can construct corresponding covariant quantities $\mathrm{X}_i$ by means of the equation.

$$\mathrm{X}_i = f_{ij} \, \mathrm{X}^j .$$

THEOREM I.

*When $\mathrm{X}_i$ is given a displacement by Synge's parallelism, $\dot{\mathrm{X}}_i$ satisfies the equation*

$$\dot{\mathrm{X}}_i = \left\{ \begin{matrix} ik \\ j \end{matrix} \right\} \mathrm{X}_j \dot{x}^k + \left\{ \overline{\begin{matrix} ik \\ j \end{matrix}} \right\} \mathrm{X}_j \ddot{x}^k$$

PROOF.

We have, $\quad d\mathrm{X}_i = \mathrm{X}^j df_{ij} + f_{ij} d\mathrm{X}^j$

$$= \mathrm{X}^j \left[ \frac{\delta f_{ij}}{\delta x^k} \, dx^k + \frac{\delta f_{ij}}{d\dot{x}^k} d\dot{x}^k \right]$$

$$+ f_{ij} \left[ - \left\{ \overline{\begin{matrix} lk \\ j \end{matrix}} \right\} \mathrm{X}^l d\dot{x}^k - \left\{ \begin{matrix} lk \\ j \end{matrix} \right\} \mathrm{X}^l dx^k \right]$$

$$= \left\{ \frac{\delta f_{ij}}{\delta x^k} - \left[ \begin{matrix} jk \\ i \end{matrix} \right] \right\} \mathrm{X}^j dx^k + \left\{ \frac{\delta f_{ij}}{\delta \dot{x}^k} - \left[ \overline{\begin{matrix} jk \\ i \end{matrix}} \right] \right\} \mathrm{X}^j d\dot{x}^k$$

on interchanging dummy indices and using I(1) and (2).

It can be seen easily that

$$\frac{\delta f_{ij}}{\delta x^k} = \begin{bmatrix} jk \\ i \end{bmatrix} + \begin{bmatrix} ik \\ j \end{bmatrix}$$

and $\quad \dfrac{\delta f_{ij}}{\delta \dot{x}^k} = \begin{bmatrix} \overline{jk} \\ i \end{bmatrix} + \begin{bmatrix} \overline{ik} \\ j \end{bmatrix} = \tfrac{1}{2} \dfrac{\delta^3 F}{\delta \dot{x}^i \delta \dot{x}^j \delta \dot{x}^k}.$

Hence it follows that

$$d X_i = \begin{bmatrix} ik \\ j \end{bmatrix} X_j dx^k + \begin{bmatrix} \overline{ik} \\ j \end{bmatrix} X_j d\dot{x}^k (i, k, j, = 1, 2, \dots n)$$

which reduce to Levi-Civita's equations for covariant components when $\begin{bmatrix} \overline{ik} \\ j \end{bmatrix} = 0$,

or, what is the same thing, the $f_{ij}$S do not contain $\dot{x}$.

The previous equations may be written

$$d X_i = \begin{Bmatrix} ik \\ j \end{Bmatrix} X_j dx^k + \begin{Bmatrix} \overline{ik} \\ j \end{Bmatrix} X_j d\dot{x}^k.$$

Dividing throughout by $ds$, the last equations may be written

$$\dot{X}^i = \begin{Bmatrix} ik \\ j \end{Bmatrix} X_j \dot{x}^k + \begin{Bmatrix} \overline{ik} \\ j \end{Bmatrix} X_j \ddot{x}^k \quad (i, j, k = 1, 2, \dots n)$$

THEOREM II.

*As in Levi-Civita parellelism, geodesics are auto-parallel curves,*

By making use of the variation principle, Synge has arrived at the equations

$$\ddot{x}^i = - \begin{Bmatrix} jk \\ i \end{Bmatrix} \dot{x}^j \dot{x}^k \quad (i, j, k = 1, 2, \dots n)$$

as the differential equations of a geodesic $x^i = x^i(s)$. Though at first sight, these appear to be the same as Levi-Civita's, here the Christoffel symbols contain $\dot{x}$, whereas in Levi-Civita's it is not so.

Let us consider a vector having the same direction as the geodesic $x^i = x^i(s)$ at every point on it. This vector can be represented by $\dot{x}^i$. Now we can write the differential equations as

$$\frac{d\dot{x}^i}{ds} = - \begin{Bmatrix} jk \\ i \end{Bmatrix} \dot{x}^j \dot{x}^k.$$

Since it can be easily seen that $\dot{x}^j \quad \dfrac{\delta f_{ij}}{\delta \dot{x}^k} = 0$,

and $\quad \dot{x}^k \quad \dfrac{\delta f_{ij}}{\delta \dot{x}^k} = 0 \quad$ ($f_{ij}$ being of zero degree in $\dot{x}$'s].

we can write the above equations as

$$\frac{d\dot{x}^i}{ds} + \left\{ \overline{\frac{jk}{i}} \right\} \dot{x}^j \ddot{x}^k + \left\{ \frac{jk}{i} \right\} \dot{x}^j \dot{x}^k = 0$$

Therefore, $\dot{x}^i$ can be considered as undergoing a parallel displacement along the geodesic. But our vector is the tangent itself ; hence the theorem.

In a paper under preparation, I write on the possibility of a covariant differentiation with the above metric.

*Reference*

[1] Transactions of the American Mathematical Society (1925).

# ON THE ABSORPTION SPECTRA OF SOME HIGHER SULPHIDES

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Amongst the polyatomic compounds, the characteristic behaviour of the Higher Oxides, $viz$., $SO_3$, $TeO_3$, $MoO_3$ and $N_2O_5$, is already known from the works of Datta and the present author[1]. In every case it was observed that the absorption is continuous beginning from a long wave limit according to a photochemical process like the following

$$TeO_3 + h\nu_1 = TeO_2 + O(^3P)$$
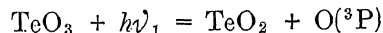
in which the products of dissociation are a normal Oxygen in the $^3P$ state, and the next lower oxide. This absorption was, however, always followed by a retransmitted patch of light with a second absorption which was attributed to a process like

$$TeO_3 + h\nu_2 = TeO_2 + O(^1D_2)$$
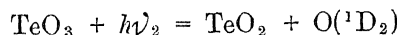
in which the liberated oxygen atom is in the metastable $^1D_2$ state. The difference $h\nu_1 - h\nu_2$, therefore, gave an experimental value of $^3P - {}^1D_2$ of Oxygen. The truth of a breaking up like the foregoing was tested in every case with the aid of thermochemical equation of the heats of formation of the oxide and the next lower oxide out of their respective constituents.

Further, it should be possible to get a third absorption in every case after another retransmitted patch of light representing the interaction of the liberated lower oxide with O in the $^1S_0$ state. But, it will be found by calculation that such an absorption would either not come at all, or appear at the limit of the quartz spectrograph where the intensity of light is very feeble. As the third transmitted patch of light itself (as found in $HgS$[2]) is very feeble it is not surprising that it was not obtained at all in the case of the oxides.

In the present investigation $TeS_3$ and $P_2S_5$ have been tried. It will be seen that in these compounds, that sulphur which belongs to the Oxygen group has been substituted for Oxygen ; and Tellurium and Phosphorous take the places of S and N in $SO_3$ and $N_2O_5$. Thus the property of the compounds have been maintained in the present case and it is expected that these sulphides would behave similarly under the action of light.

Representing all the above oxides and sulphides by a general formula of the type $M_xZ_y$, where for the present M represents Te or P, and Z for sulphur : $x$ and $y$ are 1 and 3 in $TeS_3$ and 2 and 5 in $P_2S_5$ respectively.

Therefore under the influence of light the substance should break up according to the following three processes :—

$$M_xZ_y + h\nu_1 = M_xZ_{y-1} + Z(^3P) \ldots \qquad \ldots \qquad \ldots \quad (1)$$

$$M_xZ_y + h\nu_2 = M_xZ_{y-1} + Z(^1D_2) \ldots \qquad \ldots \qquad \ldots \quad (2)$$

$$M_xZ_y + h\nu_3 = M_xZ_{y-1} + Z(^1S_0) \ldots \qquad \ldots \qquad \ldots \quad (3)$$

and the difference $h\nu_1 - h\nu_2$ and $h\nu_2 - h\nu_3$ should give approximately the values of $^3P - {}^1D_2$ and $^1D_2 - {}^1S_0$ of Z.

## EXPERIMENT

The substances were vaporised in the graphite furnace[3] of our laboratory, in which they were introduced in Pyrex glass tubes as the temperature used was never higher than 600°C. To prevent the distillation of the vapours and the wear and tear of the graphite tubes, the vacuum chamber was filled with pure Nitrogen at atmospheric pressure. A series of temperatures were tried and it was found that a temperature of 400°C was quite suitable for both the substances. The hydrogen tube run by a 2 KW transformer was used as a continuous source and the photographs were taken on an $E_3$ quartz spectrograph. Copper arc was used as comparison.

To locate the beginnings of absorption microphotograms of the plates were taken by a microphotometer belonging to the Muslim University, Aligarh. I am deeply indebted to Dr. R. K. Asundi, Reader in Physics of the Muslim University for taking the microphotograms for me, and to Dr. R. Samuel and the authorities of the Muslim University for allowing me the use of their apparatus.

## RESULTS

In both the cases of $TeS_3$ and $P_2S_5$, three regions of continuous absorption were obtained after transmitted patches of light. If the first beginning of absorption be

regarded as corresponding to $h\nu_1$, the second and third would give the values of $h\nu_2$ and $h\nu_3$.
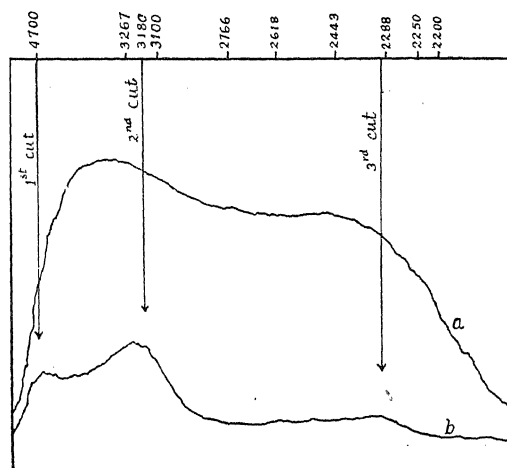


FIG. 1

$a$—Microphotogram of the continuous spectrum.

$b$—Microphotogram of the absorption spectrum of TeS$_3$.
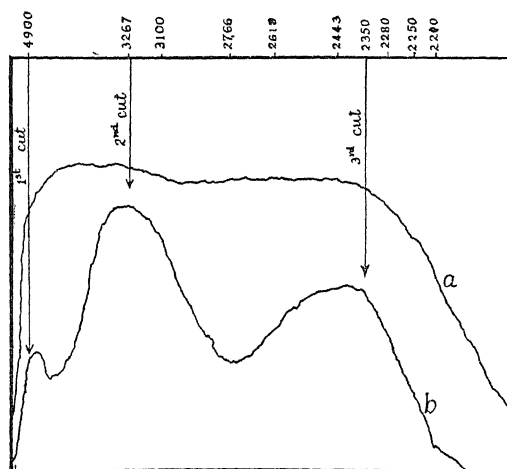


FIG. 2.

$a$ —Microphotogram of the continuous spectrum.

$b'$—Microphotogram of the absorption spectrum of P$_2$S$_5$.

For  TeS$_3$  ...    ...  $h\nu_1 = 4900$ ;    $h\nu_2 = 3261$ ;    $h\nu_3 = 3250$

P$_2$S$_5$  ...    ...  $h\nu_1 = 4700$ ;    $h\nu_2 = 3180$ ;    $h\nu_3 = 2300$.

The mean value of $h\nu_1 - h\nu_2 = 1{\cdot}3$ volts and that of $h\nu_2 - h\nu_3 = 1{\cdot}5$ volts giving respectively the values of $^3P - {}^1D_2$ and $^1D_2 - {}^1S_0$ of sulphur. The same values were obtained in the work on the sulphides of zinc, cadmium, and mercury (loc. cit) by the present author.

The position of the first beginning of absorption $h\nu_1$ could not be tested thermo-chemically as no data are available.

The author wishes to express his indebtedness to Prof. M. N. Saha, D.Sc., F.R.S., under whose guidance this work was carried out.

### References

[1] Datta and Sen-Gupta, *Proc. Roy Soc.* A, Vol. 139, p. 397, (1933)

[2] Communicated to the Royal Society, London.

[3] Desai, *Proc. Roy. Soc.* A, Vol. 136, p. 76, (1932)

# CHEMICAL EXAMINATION OF THE SEEDS OF *ABRUS PRECATORIUS*, LINN. PART II. THE COLOURING MATTER OF THE SEED-COAT

By Narendranath Ghatak

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In a previous paper[1] by Ghatak & Kaul the results of Chemical Examination of the kernels of the seeds of *Abrus precatorius* (scarlet variety) have been recorded. In the present paper the method of isolation and properties of the red colouring matter of the seeds have been described. The first attempt towards the isolation of the colouring matter of *Abrus* seeds was made by Sarkar[2], who extracted two colouring matters, yellow and scarlet, by soaking the crushed seed-coat in water and finally separating them with ether. He purified the scarlet colouring matter by preparing the insoluble copper salt and from a study of some colour reactions concluded it to be a tannin substance. The next reference that "anthocyanin is some times developed in the cells of the testa of seeds of *Abrus*" is recorded in Onslow's book (The Anthocyanin Pigments of Plants, 1925, p. 30).

The above represents all that exist in chemical literature about the colouring matter of *Abrus* seeds and no definite observations have yet been made regarding

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the exact nature of its chemical constitution. The present author has, however, been able to seperate in pure forms a red anthocyanin and gallic acid from the seed-coat of *Abrus precatorius*. The methods of isolation and properties of these substances have been described in the experimental part of the paper.

## EXPERIMENTAL

The seed-coat of *Abrus precatorius* constitutes 30 % of the weight of the entire seed. The inner surface of the seed-coat is yellowish white and gives out a thin inner integument on soaking with water. If a portion of the seed-coat, from which the inner integument has been removed, is dipped in neutral ferric chloride solution, the inner side immediately takes up a blue stain and the upper red side is slowly affected. This shows the presence of a layer of tannin matter after the inner integument. In the next layer is present the red colouring matter and at the top is a thin cuticle which imparts polish to the red colour of the seed. The colouring matter slowly passes into solution when kept soaked in water but the colour of the solution is discharged on standing. On addition of acids the solution becomes bright pink red. A similar treatment as above with alcohol keeps the colouring matter in the seed-coat unaffected. But if some of it is previously treated with water, dried and then treated with alcohol, the colouring matter is readily extracted. This proves definitely the presence of a thin cuticle at the top of the seed which is quickly removed by water.

In aqueous-acid solutions the colour is readily extracted but concentrated hydrochloric and glacial acetic acids do not dissolve it. The pink colour of dilute acid extracts is readily discharged becoming brownish yellow on addition of alkali. An aqueous extract of the seed-coat develops a bluish black colouration with ferric chloride, which turns bluish-violet on dilution. When the seed-coat is allowed to remain long in aqueous hydrochloric acid, the black spots slowly lose colour becoming pink-red and then brown, the other portions turning white. This shows that the black spot of the seed-coat is only a very concentrated form of the red colouring matter which exists all around.

## EXTRACTION OF THE COLOURING MATTER

The seeds of *Abrus precatorius* were partially crushed in a hand crushing machine when the seed-coat was easily detached from the hard yellow kernels.

400 g. of the seed-coat thus obtained was crushed to small pieces and extracted with boiling water in a porcelain dish. After about ten minutes boil the extract, which was of a pale pink colour, was filtered. On addttion of a few drops of hydrochloric acid the colour of the extract became deep pink red. Excess of solid lead acetate was then added and a flocculant bluish-white precipitate was formed which was filtered off. The material was again extracted with fresh quantity of boiling water and precipitation repeated as before. This process was repeated till the seed-coat became almost colourless and the black spots turned brown. The colour of the lead salts of subsequent extracts improved towards blue. The combined lead salt was washed with hot water and the cake macereted with 500 c.c. of glacial acetic acid in a porcelain mortar. The lead salt of the colouring matter dissolved with deep pink red colour. It was filtered and the residue was again taken up with a further quantity of 300 c.c. of glacial acetic acid. To the total acetic acid extract ether was added till the pink colour of the solution just disappeared. A blue precipitate of the lead salt of the colouring matter was formed. Excess of ether was avoided as it precipitated a white substance. The lead salt was filtered, washed several times with ether and finally with alcohol to free it from acetic acid. On drying, the blue colour of the salt changed to yellowish-green. It was decomposed in ethyl alcohol (98%) suspension with concentrated hydrochloric acid. The alcoholic solution became deep red and lead chloride settled at the bottom. The filtrate was kept with three volumes of ether for 48 hours. The colouring matter settled at the bottom. The mother liquor was decanted off and the residue on washing several times with dry ether was obtained as dark red crusts. It is proposed to designate this substance *abranin* with reference to its being an anthocyanin and the generic name of the plant from which it has been obtained.

A portion of the filtrate from the original lead salt was freed from lead and acetic acid was neutralised with ammonia and concentrated. The solution reduced Fehling's solution, ammoniacal silver nitrate and copper acetate solution in dilute acetic acid. From this solution an osazone was prepared in the usual way and was identified to be glucosazone, m. p. 205°.

The filtrate from the glacial acetic acid extract of the original lead salt that was precipitated with ether, was concentrated to about 100 c.c. A thick dirty white precipitate was formed. It was washed free from acetic acid, dried and decomposed in alcoholic suspension with dilute sulphuric acid. The filtrate on complete evaporation of the solvent deposited needle shaped crystals (4g.). It was recrystallised from hot water and animal charcoal. Small needle shaped soft silky crystals were obtained which on drying in air oven melted at 262°. This substance on heating with concentrated sulphuric acid produces a purple coloration.

Potassium cyanide solution developes a pink colour with the substance which disappears on standing but returns back on shaking with air. Lime water produces a blue coloration with it. The white lead salt of the substance produces a carmine-coloured precipitate with caustic potash which dissolves in excess to a raspberry-red solution. It does not coagulate gelatine solution. The substance was, therefore, identified to be gallic acid as it responded to all its characteristic reactions. It gave a mixed melting point with the pure Merck's gallic acid at 262-263°. [Found : C, 49.22 ; H, 3.68 ; M. W., (decomposition of lead salt), 169. Gallic acid requires, C, 49.41 ; H, 3.53 : M. W., 170].

*Properties of abranin chloride* : The crude chloride as prepared above, was extracted several times with ether to remove gallic acid and ether soluble impurities. It was dissolved in 0·5% hydrochloric acid-ethyl alcohol, filtered and kept with two volumes of ether in the refrigerator. The colouring matter settled at the bottom as thin microscopic plates. The mother liquor retained some of the colouring matter which could not be thrown down even on addition of more ether. The precipitated abranin chloride was filtered and washed with ether and dried in vacuum desiccator over calcium chloride for three days. It was of a dark violet-red colour and melted at 178-179° with previous sintering. In neutral solvents like methyl and ethyl alcohols, water etc. it dissolves and readily isomerises becoming violet and on long standing the colour is completely discharged. In presence of traces of acids it is very soluble in methyl alcohol and comparatively less so in ethyl alcohol. In alkalies it dissolves with deep yellow coloration. Pink red colour of abranin chloride in water becomes blue on addition of sodium carbonate and violet on addition of sodium acetate. With copper acetate solution it gives a blue precipitate and neutral ferric chloride changes the pink colour of the solution to brown and then to yellow. In concentrated sulphuric acid abranin chloride dissolves with orange red colour, which on dilution becomes pink red. An aqueous-alcoholic 50% extract of the chloride gives with dilute solution of aluminium chloride a blue colour. On combusting the substance the following results were obtained : C, 50.06 ; 50.12 ; H, 5.33, 5.41.

*Hydrolysis of abranin chloride* : 0.5g. of the substance was dissolved in dilute hydrochloric acid and warmed with further addition of concentrated hydrochloric acid (making the strength about 10-12%). On allowing it to cool small quantity of dark red granular powder settled. It was filtered, washed and dried in vacuum desiccator over calcium chloride. It did not melt even on heating to 300° and was the aglucone—abranidin. Small quantity of abranidin that remained in the mother liquor could not be induced to separate from solution. It was, therefore, quantitatively removed by extraction with amyl alcohol. The aqueous solution was neutralised

and the osazone of the sugar prepared. The phenylosazone melted at 205° and was identified to be glucosazone.

*Abranin picrate* : 0.5g. of the chloride was dissolved in water and to it was added hot saturated solution of picric acid. The brown solution slowly deposited chocolet-red plates of the picrate along with crystals of picric acid on spontaneous evaporation of the solvent. The precipitate was dried and washed several times with dry ether to completely remove picric acid. The picrate was soluble in water. It melted at 149-50° after being dried in vacuum desiccator over calcium chloride.

*Distribution Number* : The distribution number was determined according to the method of Willstätter and Zollinger (Annalen, 1916, *412*, 208) using pyridine-free amyl alcohol saturated with an equal volume of 0·5% aqueous hydrochloric acid. 0·01g. of the pigment was dissolved in 50c.c. of 0·5% aqueous hydrochloric acid. The solution was extracted with 50c.c. amyl alcohol twice and the distribution numbers were determined with comparison of a standard solution of the pigment in amyl alcohol by means of a colorimeter. The first extraction gave the distribution number 11·13 and the second, 10·42. From these results the anthocyanin is concluded to be a mono-glucoside.

*Absorption spectra* : 0·01g. of the pigment was dissolved in 50c.c. of methyl alcohol-hydrocloric acid and the absorption spectra were determined in a constant deviation spectrometer (Adam Hilger). The comparison spectrum that has been taken above the continuous and absorption spectra is that of copper arc. The time of exposures of the continuous and arc spectra were the same. The absorption spectrum consists of one broad band reaching from the yellow to blue. The end of the bigger wavelength of the absorption band is fairly well defined, more so when long columns are examined than when shorter ones are used. The edge of the smaller wavelength of the absorption band is very ill-defined. The absorption spectra photo and the absorption data are as follows :—

No.                                                              Absorption.

1.  Continuous spectrum
2.  Thickness of layer exposed 2·5 mm.   516...513 — 493...491.
3.      „           „      „        5·0 mm.   551...548 — 486...483.
4.      „           „      „       10·0 mm.   570...569 — 476...469.
5.      „           „      „       20·0 mm.   579 to the end of the visible region.

*References*

[1]  Ghatak and Kaul, *J. Indian Chem. Soc.*, **9**, 383, 1932.

[2]  Sarkar. *Biochem. J.*, **8**, 281, 1914.
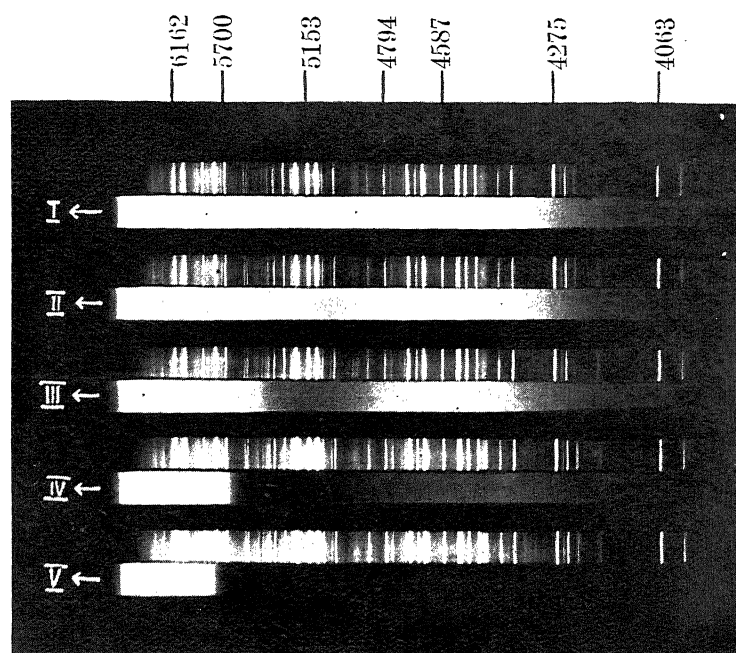
Absorption spectra photo of abranin chloride in methyl alcohol-
hydrochloric acid solution.

# A NOTE ON THE OPTICAL ACTIVITY OF THE ALKALOIDAL SALTS OF VIOLURIC ACID

By NARENDRANATH GHATAK

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In a paper Stewart[1] has shown that there exists a close relation between the unsaturation, absorption spectra and rotatory power of a substance. He found that greater the absorption spectra of a substance the greater the magnatic rotatory power it will have, and also the greater unsaturated the molecule is, the greater will be its rotatory power. In fact in his experiments he has shown that on removing the unsaturation the rotatory power is also similarly changed thus :—

| Substance. | | | Rotation $\left[M\right]_{D}^{20}$ |
|---|---|---|---|
| $\beta$ – Phenylpropionic ester | ... | ... | $+4\cdot98$ |
| Cinnamic ester ... | ... | ... | $16\cdot36$ |
| Phenylpropiolic ester | ... | ... | $12\cdot05$ |

But all the works of Stewart was confined to substances which have got an ultra-violet absorption and at that time no compound was known which was coloured as well as optically active. Singh[2] has prepared some coloured camphor compounds and has substantiated the statement of Stewart as regards the relation between absorption and rotatory power.

In the course of experiments conducted for the preparation of different violurates, in order to elucidate the constitution of violuric acid[3], the author had to prepare some salts of the acid with different alkaloids. These salts retained the property of optical activity to a considerable extent.

It has been shown by many chemists that, $-CH=N-$, is a negative unsaturated group and it has been shown by Tewari and Dutt[4] that this unsaturation brings about more colour to a compound. But supposing that this state of unsaturation is decreased then according to Tewari and Dutt the compound would be less coloured ; and if they be optically active then according to Stewart[1] they will have less rotatory power than the corresponding unsaturated compound.

It is well known that in many of the alkaloids there is a group $-CH=N-$ and as soon as the salt formation takes place the two latent valencies of the nitrogen atom are satisfied thus :—

after salt formation →
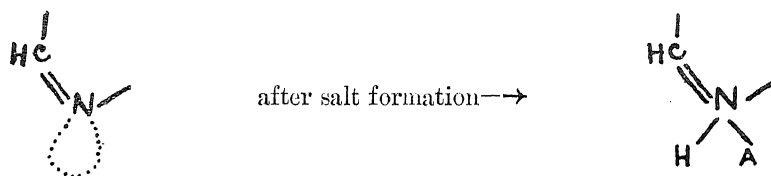
and hence the strain on it is removed. Therefore an alkaloidal salt should have less rotatory power than the alkaloid (free base). This has been verified to be true from the investigations of the present author. The results are given in the experimental part of the paper. The following alkaloids have been condensed with violuric acid,—nicotine, morphine, brucine, strychnine, cinchonine, quinine and cocaine. The optical measurements were done with violurate solutions immediately after taking the absorption spectra photos. The source of illumination in absorption spectra and optical rotation determinations was copper arc and sodium flame respectively.

EXPERIMENTAL

The salts of violuric acid described in this paper were prepared by mixing equimolecular proportions of the acid and the organic base in alcoholic solution. The mixture was put in a flat bottomed dish and kept for spontaneous evaporation of the solvent at room temperature, when large well developed crystals were slowly formed. These were then re-crystallised from water or dilute alcohol. All the salts without exception crystallised in fine long needles or flowery clusters with silky lustre. In physical appearance they are either violet, pink or blue. All of them dissolve in water or organic solvents like alcohol, acetone etc. with various shades of pink colour. The salts do not contain any solvent of crystallisation and are exceedingly pure, as is confirmed by a number of analytical data given in Table I. Most of them undergo decomposition when heated to 85°, and the same thing happens when they are exposed to atmospheric conditions for a long time.

TABLE I.

| Name of the salt (V = Violurate) | | Appearance | Colour in aqueous solution | Analytical data (theoretical in brackets) |
|---|---|---|---|---|
| 1. | Nicotine V. ... | Blue | Deep pink | N = 23·1(23·5%) |
| 2. | Morphine V. ... | Light blue | do | ... |
| 3. | Brucine V. ... | Violet | do | ... |
| 4. | Strychnine V. ... | Blue | Violet pink | N = 14·0(14·3%) |
| 5. | Cinchonine V. ... | Pink | Pale pink | N = 15·2(15·5%) |
| 6. | Quinine V. ... | Violet | do | ... |
| 7. | Cocaine V. ... | Blue | Deep pink | N = 12·1(12·2%) |

TABLE II.

| Substance | | Specific rotation $\left[a\right]_D^{30}$ | Absorption maxima $(\lambda)$ at N/128 dilution. |
|---|---|---|---|
| | Nicotine ... ... | ... − 161·5 | ... ... |
| 1. | Nicotine Violurate ... | ... − 65·5 | ... 5695 |
| | Morphine ... ... | ... − 70·0 | ... ... |
| 2. | Morphine Violurate ... | ... − 43·7 | ... 5691 |
| | Brucine ... ... | ... − 120·0 | ... ... |
| 3. | Brucine Violurate ... | ... − 69·0 | ... 5679 |
| | Strychnine ... | ... ...... | ... ... |
| 4. | Strychnine Violurate ... | ... − 8·3 | ... 5660 |
| | Cinchonine ... | ... + 229·0 | ... ... |
| 5. | Cinchonine Violurate ... | ... + 140·0 | ... 5557 |
| | Quinine ... ... | ... − 142·0 | ... ... |
| 6. | Quinine Violurate ... | ... − 70·9 | ... 5537 |
| | Cocaine ... ... | ... − 15·0 | ... ... |
| 7. | Cocaine Violurate ... | ... − 12·3 | ... 5674 |

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*References*

[1] Stewart, A. W., *J. Chem Soc.*, pp. 199—209, 1907.

[2] Singh and Rai, *J. Indian Chem. Soc.*, **3**, 389, 1926.

[3] Ghatak and Dutt, *J. Indian Chem. Soc.*, **5**, 665, 1928.

[4] Tewari and Dutt, *J. Indian Chem. Soc.*, **3**, 161, 1926 ; **4**, 201, 1927.

# ABSORPTION SPECTRA OF COLOURED ORGANIC SALTS OF VIOLANTIN AND ALLOXANTIN

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In a paper by one of the present authors[1], the absorption spectra of coloured organic salts of violuric acid were investigated leading to the general conclusion that the stronger the base, the greater is the intensity of absorption of the corresponding salt with violuric acid. This led us to examine a large number of organic acids which give coloured salts with organic bases with the result that finally two substances—violantin and alloxantin—were selected for the sake of determining the absorption spectra of their organic salts.

Violantin is a chemical combination of one molecule of violuric acid or isonitroso-malonylurea with one molecule of dilituric acid or nitro-malonylurea, and is a colourless crystalline substance of weakly acidic nature. It is gradually hydrolysed by water into its constituents, and therefore salt formation between this substance and organic bases was done in alcoholic medium. Alloxantin on the other hand is a fairly strong acid and its salts are not hydrolysed to any great extent by water. Both these substances behave like monobasic acids and combine with one molecule of organic base to form salts.

The salts of violantin and alloxantin are all highly coloured substances which show well defined absorption bands between wave lengths 4600 and 5600, in alcoholic solutions, in which they do not undergo any hydrolytic decomposition. To the unaided eye, the colour of these substances in solution appears to be different shades of pink and violet. Most of these salts crystallise in well defined shapes, but some are micro-crystalline also. They do not contain any water or alcohol of crystallisation. The taste of them is intensely bitter.


EXPERIMENTAL

Salts of violantin and alloxantin with organic bases were obtained by taking equimolecular proportions of the acidic and basic constituents separately in alcoholic solutions, mixing the two solutions together, and then gradually allowing the solvent to evaporate at the ordinary temperature, when masses of coloured crystals gradually separated. They were filtered off and freed from the adhering mother liquor by washing with benzene and ether and finally recrystallised from 70% alcohol.

These salts are generally fairly soluble in alcohol, acetone and acetic acid and also in water with slight hydrolytic decomposition. They are sparingly soluble in benzene and almost insoluble in ether, chloroform and ligroin. The salts of violantin and alloxantin do not give any definite melting points as they are gradually decomposed in the process by heating. The absorption spectra of these substances have been determined by a constant deviation glass spectrograph by Adam Hilger. For the sake of abbreviation, the properties of these substances including absorption maxima have been given in tabular forms at the end of the paper. The properties of these substances in general are closely analogous to those derived from violuric acid (loc. cit), but so far as their intensity of colour is concerned they are much weaker. This will also be apparent from the tables of absorption maxima given at the end of the paper.

## TABLE I

*Organic Salts of Violantin*

| Salt with. | Appearance. | Colour in alcoholic Solution. | Absorption maxima ($\lambda$) | Analysis. (Theoretical values in brackets.) |
|---|---|---|---|---|
| Methylamine ... | Dark violet needles | Reddish Violet | 5540 | N = 27·5 (27·1) % |
| Ethylamine ... | ,,   ,,   ,, | ,,   ,, | 5490 | N = 26·3 (26·1) ,, |
| Diethylamine ... | Violet red   ,, | Crimson | 5450 | N = 24·8 (24·3) ,, |
| Triethylamine ... | ,,   ,,   ,, | ,, | 5290 | N = 22·2 (22·7) ,, |
| Aniline ... | Bluish-green   ,, | Pink | 5100 | N = 23·5 (23·16) ,, |
| O—toluidine ... | Violet   ,, | ,, | 5080 | N = 22·7 (22·3) ,, |
| M—toluidine ... | Bluish-violet   ,, | ,, | 5080 | N = 22·5 (22·3) ,, |
| O—anisidine ... | Indigo-blue   ,, | ,, | 5080 | N = 22·0 (21·6) ,, |
| P—anisidine ... | ,,   ,, | ,, | 5080 | N = 21·7 (21·6) ,, |
| O—phenetidine ... | ,,   ,, | ,, | 5050 | N = 21·3 (20·9) ,, |
| P—phenetidine ... | ,,   ,, | ,, | 5050 | N = 21·2 (20·9) ,, |
| Methylaniline ... | Violet   ,, | ,, | 5040 | N = 22·8 (22·3) ,, |
| Ethylaniline ... | ,,   ,, | ,, | 5020 | N = 22·2 (21·7) ,, |
| O—phenylenediamine | Dark-violet   ,, | Reddish Violet | 5150 | N = 25·9 (25·5) ,, |
| M—phenylenediamine | ,,   ,, | ,,   ,, | 5130 | N = 25·1 (25·5) ,, |
| P—phenylenediamine | ,,   ,, | ,,   ,, | 5080 | N = 25·5 (25·5) ,, |
| Nicotine ...   ... | Blue   ,, | ,,   ,, | 5490 | N = 22·9 (22·7) ,, |
| Cinchonine ... | Pink   ,, | Pink | 5400 | N = 18·3 (17·9) ,, |
| Brucine ...   ... | Violet-red   ,, | ,, | 5320 | N = 15·9 (15·4) ,, |
| Narcotine ... | ,,   ,, | ,, | 5190 | N = 12·8 (13·1) ,, |
| Morphine ... | Blue   ,, | ,, | 5290 | N = 16·3 (15·9) ,, |
| Codeine ...   ... | ,,   ,, | ,, | 5320 | N = 15·5 (15·5) ,, |

## TABLE II

*Organic Salts of Alloxantin*

| Salt with | Appearance | Colour in alcohol | Absorption maxima λ) | Analysis, (Theoretical values in brackets) |
|---|---|---|---|---|
| Ethylamine ... | Dark violet needles | Deep pink | 5400 | N = 22·1 (22·0) % |
| Triethylamine ... | Reddish violet ,, | ,, ,, | 5380 | N = 18·6 (18·9) ,, |
| Methylaniline ... | Light violet ,, | Pink | 5200 | N = 18·3 (18·6) ,, |
| Ethylaniline ... | Orange-brown ,, | Red | 5180 | N = 18·02 (17 9) ,, |
| O-toluidine ... | Brown ,, | ,, | 5080 | N = 18 2 (18·6) ,, |
| M-toluidine ... | ,, ,, | ,, | 5080 | N = 18·5 (18·6) ,, |
| O-phenetidine ... | Brownish-violet ,, | Deep red | 5150 | N = 17·3 (17·2) ,, |
| P-phenetidine ... | ,, ,, ,, | ,, ,, | 5080 | N = 17·6 (17·2) ,, |
| O-anisidine ... | Brownish red ,, | ,, ,, | 5180 | N = 17·9 (17·99) ,, |
| P-anisidine ... | ,, ,, ,, | ,, ,, | 5090 | N = 17·8 (17·99) ,, |
| Nicotine ... | Dark violet ,, | Crimson | 5380 | N = 19·2 (19·5) ,, |
| Narcotine ... | Orange red ,, | Pink | 5080 | N = 10·6 (10·2) ,, |
| Morphine ... | Reddish-violet ,, | Crimson | 5250 | N = 12 4 (12·6) ,, |
| Brucine ... | Deep pink needles | Pink | 5130 | N = 13·1 (12·7) ,, |
| Cinchonine ... | Crimson ,, | ,, | 5160 | N = 14·7 (14·9) ,, |
| Codeine ... | Dark red ,, | ,, | 5070 | N = 12·6 (12·3) ,, |
| Cotarnine ... | Red ,, | Red | 5020 | N = 14·1 (13 8) ,, |

*Reference*

[1] Ghatak and Dutt, *J. Indian Chem. Soc.*, **5**, 665, 1928.

# CHEMICAL EXAMINATION OF THE LEAVES OF *NYCTANTHES ARBORTRISTIS, LINN*

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*Nyctanthes arbortristis*, known as "Shieuli" in Bengali and "Harsinghar" in Hindusthani is a plant of the natural order of Oleaceae. It is a comparatively small deciduous tree, not more than 30 feet in height and generally cultivated throughout India for the sake of its sweet scented flowers and also for its bitter leaves having medical properties. According to Sanskrit writers the leaves are useful in obstinate fevers, rheumatism and billious affections and are particularly efficacious in expelling intestinal worms. More recently, Col. Hooker, Major Basu and others have also testified to the efficacy of the leaves in these directions.

The presence of an alkaloidal principle—"Nyctanthine" was claimed by the previous workers. In addition to an alkaloid, the presence of a trace of an oily principle having a taste somewhat similar to peppermint, an astringent principle, a resin and a reducing sugar was claimed. (Dymock, Pharm. Indica, Vol. II, 378.)

The above represents the work that has been done on the leaves of *Nyctanthes Arbortristis*. The present author made a systematic examination of the leaves with the hope of isolating the alkaloid from them. But unfortunately the claim of the previous workers in this direction could not be substantiated. However, as the result of the investigation 1.3% of crystalline mannitol, 1% of an amorphous glucoside and 1.2% of a resin were isolated and the presence of a trace of a volatile oil and 0.48% of reducing sugar (mainly glucose) has been shown.

## EXPERIMENTAL

The full grown leaves were collected in the month of October just before they began to fall on the advent of winter and were dried in the air in the shade

for a month. They thereby lost nearly 23% of moisture by the process. The dried leaves when completely burnt left 18.2% of a greyish white ash containing 91.2% of water-insoluble and 9.8% of water-soluble inorganic constituents. The following elements and radicals were detected in the ash : sodium, calcium, magnesium, iron, silica, alumina, carbonate, chloride, phosphate and sulphate (the last two in traces). The leaves were then extracted with various solvents in a Sohxlet's extraction apparatus.

*Petroleum ether extract* 3.28%. Dark green sticky mass, smelling strongly of chlorophyll. Does not reduce Fehling's solution. Consists mainly of chlorophyll, wax and resin.

*Benzene extract* 3.99%. Properties similar to the above.

*Alcoholic extract* 14.7%. Dark yellowish green syrup, strongly smelling of chlorophyll. Reduces Fehling's solution and gives faint colour reactions with many of the alkaloid reagents. Gives precipitates with lead acetate, cadmium chloride, silver nitrate and ferric chloride.

*Aqueous extract* 6.2%. Dark brown syrup, smelling strongly of sugars. Reduces Fehling's solution very readily and gives precipitates with lead acetate. Contains sugars and tannins. No colour reactions with alkaloid reagents.

One kilo of the powdered dry leaves were repeatedly extracted with benzene in a large extraction apparatus until the chlorophyll was practically completely removed. From the benzene extract only a green sticky mass was obtained on distilling off the benzene, and from it by successive extractions with different solvents nothing definite could be isolated. A portion of it was treated with dilute hydrochloric acid and the solution tested with alkaloid reagents, but with negative results.

After the removal of chlorophyll, the powdered leaves were extracted with alcohol till the extract had only a light yellow colour. The combined alcoholic extracts were concentrated at the ordinary pressure to nearly 1/10th their original volume, and on keeping over-night it became filled with long needle shaped crystals. A portion of this concentrated alcoholic extract was treated with dilute hydrochloric acid and then with a number of alkaloid reagents with the following results :—

| | | | |
|---|---|---|---|
| Picric acid | ... | ... | ... no change |
| Sodium carbonate | ... | ... | ... „ „ |
| Meyer's reagent | ... | ... | ... „ „ |
| Phosphomolybdic acid | ... | | ... green coloration. |
| Phosphotungstic acid | ... | | ... gelatinous ppt. |
| Dragendrof's reagent | ... | | ... slight turbidity. |
| Froehde's reagent | ... | ... | ... reddish brown ring. |
| Erdmann's reagent | ... | ... | ... reddish brown ring. |

The sticky alchoholic mother liquor containing masses of crystals could not be filtered even at the pump on account of its viscosity as it contained a large amount of resinous matter. It was therefore repeatedly extracted with chloroform which removed the resinous substances and left the alcoholic mother liquor with the suspended crystals in a much thinner and filterable condition. The crystals on filtration were washed with cold alcohol uutil colourless and dried in the steam oven. They melted at 165-166° and on recrystallisation from absolute alcohol the melting point did not rise any higher. The substance burnt with a non-smoky flame with the odour of burnt sugar and did not reduce Fehling's solution, although Tollen's reagent was reduced fairly easily. It was identified to be mannitol by its physical and chemical properties and also by its mixed melting point with Merck's pure mannitol, which remain at 165-166°. (Found $C = 39.41$ ; $H = 7.75$ ; $C_6H_{14}O_6$ requires $C = 39.55$; $H = 7.69\%$). Melting point of the hexaacetate prepared by the action of acetic anhydride and sodium acetate on the substance was found to be 119° which is also the melting point of mannitol hexaacetate.

The choloroform extract mentioned above on evaporation yielded a greenish brown resinous mass from which benzene removed a trace of chlorophyll. The residue on drying became a brittle yellowish brown resin. It dissolves partially in hot water forming an opalescent solution giving a dirty white precipitate with lead acetate. It gives only a pale yellow coloration with strong sulphuric acid and no violet coloured ring with $\alpha$-naphthol, choloroform and strong sulphuric acid, thereby proving the absence of glucosides. It reduces Fehling's solution and ammoniacal silver nitrate on warming.

The dark brown alcoholic mother liquor left after the separation of mannitol was concentrated to a small volume and extracted with petroleum ether from which a trace of a volatile oil having a characteristic taste and smell was recovered on evaporation. The residual alcoholic mother liquor was then treated with alcoholic lead acetate when a voluminous bright yellow precipitate was formed. This was filtered, thoroughly washed with hot water and then with hot alcohol. The lead compound was then decomposed by hydrogen sulphide in cold alcoholic suspension. The precipitated lead sulphide was filtered off and from the filtrate the dissolved hydrogen sulphide was driven off by passing carbon dioxide. Finally, the alcoholic liquid was completely evaporated, the final stages being done under high vacuum. A yellow amorophous exceedingly bitter mass was obtained which was purified by extraction with a mixture of two parts of ethylacetate and one part of acetone. On complete evaporation of the mixed solvent under high vacuum, a pale yellow amorphous mass was obtained, melting at 71°. It burns with a smoky flame and without the smell of burnt sugar. It is easily soluble in water and alcohol, less so in ethyl acetate and insoluble in benzene, choloroform and petroleum ether. It gives a green coloration with ferric chloride, a bright yellow granular precipitate with lead

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acetate and an orange coloration with caustic soda and ammonia. It is slightly hygroscopic, and has a persistent bitter taste. It does not coagulate gelatine solution, but gives a pale yellow bromo-derivative with bromine water. In short, all the properties of this substance point to its being a glucoside (Found : $C = 48\cdot8$ ; $H = 4\cdot87\%$ and Pb in the lead salt $= 44\cdot64\%$). The substance reduces Fehling's solution on hydrolysis.

The filtrate and washings from the lead were concentrated and the reducing sugars estimated by means of Fehling's solution, showing the presence of $0\cdot48\%$ of reducing sugars. The osazone was prepared in the usual manner and was found to be identical with phenyl-glucosazone, M. P. 206°.

# ON THE ABSORPTION SPECTRA OF SOME SATURATED HALIDES

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Saturated halides fall into three distinct groups according to nature of their absorption spectra. This has been summarised by Franck (1) as follows :—

(1) ALKALI-HALIDE TYPE. These show continuous absorption beginning at a long wave-length limit. This limit corresponds to the heat of dissociation of the molecule. The binding for these molecules is ionic.

(2) HYDROGEN-HALIDE TYPE. These show continuous absorption but the long wave-length limit does not correspond to the heat of dissociation of the molecule.* This limit lies as a matter of fact on the ultra violet side of the critical wave-length. For these substances the binding is said to be atomic ; at least partly.

(3) AgCl AND ThCl TYPE. These give band absorption as well as continuous absorption. The same type of absorption has been found for the halides of the alkaline earths by Deb and Mukerji (2). These workers ascribe the band absorption to ths presence of metastable d-levels in the atoms of the alkaline earths.

The case of the poly-halides has received attention from some workers (3) recently ; and a number of papers have appeared wherein attempts have been made to extend Franck's ideas on the absorption of the alkali halides. Datta and Saha in particular, have suggested that the long wave-length limit of the absorption is approximatejy given by a generalization of Franck's relation, *viz.*

$$h\nu = R/N$$

where N is the number of the halogen atoms in the molecule and R is the atomic heat of formation of the molecule.

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* A. K. Dutta has recently (Zeit- f. Phy. 77, 404, 1932) measured the extinction coefficients for HBr. and HI and finds that for these also the beginning of absorption, where the coefficient is asymptotically zero, corresponds to the heat of dissociation of the molecules of HBr and HI,

R can be calculated from the relation

$$R = Q + \frac{n}{2} D_{X_2} + L_M - L_{MX_n}$$

where Q is the heat of formation obtained from thermo-chemical measurements.

$D_{X_2}$.    = the heat of dissociation of the halogen molecule

$L_M$      = the heat of vaporization of the metal

$L_{MX_n}$   = the heat of vaporization of the compound. The present series of experiments were undertaken in continuance of this line of work. The substances studied are all saturated poly-atomic halides and the preliminary results are reported in this paper.

The substances so far studied are $BCl_3$, $BBr_3$, $SiCl_4$, $SiBr_4$. $TiCl_4$, $TiBr_4$, $SnCl_4$, $SnBr_4$, $TeCl_4$, $TeBr_4$ and $PCl_5$.

These substances naturally fall into two groups depending on the fact that some of these are liquids at ordinary temperatures and thus give sufficient vapour for absorption while there are others whose melting points are higher ; but in no case higher than 380°C. The following table shows the melting and boiling points for these substances.

TABLE 1.

| Substance | | Melting point | Boiling point |
|---|---|---|---|
| $BCl_3$ | ... | ... | ... |
| $BBr_3$ | ... | ... | ... |
| $SiCl_4$ | ... | 68.1°C | 157·5°C |
| $SiBr_4$ | ... | 5°C | 153°C |
| $TiCl_4$ | ... | 25°C | 135°C |
| $TiBr_4$ | ... | 39°C | 135°C |
| $SnCl_4$ | ... | 33°C | 114°C |
| $SnBr_4$ | ... | 29·5°C | 206°C |
| $TeCl_4$ | ... | 214°C | 414°C |
| $TeBr_4$ | ... | 380±6°C | 414-427°C |
| $PCl_5$ | ... | 148°C (under pressure) | |

## EXPERIMENT

For the first class the absorption chamber was simply a glass tube about a metre long. Two ends of this chamber were closed with quartz windows. The liquids were kept in a bulb which was connected to the absorption chamber by a side tube. Another side tube connected the chamber to a pump which served to evacuate it. This was necessary since most of these substances fume heavily in presence of moist air.

For the second class the absorption chamber was a pyrex tube round which nichrome wire was wound. This formed a furnace which could be heated with electric current to any desired temperature. An $E_3$ quartz spectrograph was used to photograph the spectrum. The source of continuous light was a hydrogen tube run by a 3KW transformer. Microphotograms for some plates were taken by Mr. H. K. Trivedi at the science laboratories, Patna. My thanks are due to him as well as to authorities of the Patna laboratories for permission to use their microphotometer.

## RESULTS

In each case there is a continuous absorption beginning at a long wave-length limit without any trace of band structure. In a few cases there were one or two re-transmissions. The following table shows the beginning of absorption for the different substances.

TABLE 2.

| Substance | Beginning of first absorption. | Beginning of second absorption. | Beginning of third absorption. |
|---|---|---|---|
| $BCl_3$ ... | 2370A | ... | ... |
| $BBr_3$ ... | 2770A | ... | ... |
| $SiCl_4$ ... | 2510A | ... | ... |
| $SiBr_4$ ... | 2650A | ... | ... |
| $TiCl_4$ ... | 3280A | ... | ... |
| $TiBr_4$ ... | 3760A | 3060A | 2490A |
| $SnCl_4$ ... | 3400A | 2750A | ... |
| $SnBr_4$ ... | 3510A | ... | ... |
| $TeCl_4$ ... | 4540A | ... | ... |
| $TeBr_4$ ... | 4600A | ... | ... |
| $PCl_5$ ... | 4200A | ... | ... |

## CALCULATIONS

We can suppose that the primary action of light absorption by the molecule in the case of continuous absorption is to remove one of the halogen atoms from the rest of the molecule according to the equation :—

$$MX_n + h\nu = MX_{n-1} + X$$
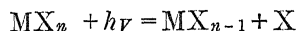
According to the generalized Franck's relations this $h\nu$ is equal to $R/n$ where R is the atomic heat of formation of the molecule. The thermo-chemical data required to calculate the atomic heats of formation of the molecules were taken from the international critical tables and the tables of Landolt and Bornstein. These are tabulated below :—

TABLE 3.

| Substance. | $Q$ KCal | $\frac{n}{2}D_{X_2}$ KCal | $L_M$ KCal | $L_{MX_n}$ KCal | $R$ KCal |
|---|---|---|---|---|---|
| BCl$_3$ ... | (88) gas. | 87 | 80?... | ... | 255·8 |
| BBr$_3$ ... | (42·6) liq. | 69 | 80? | ... | 192 |
| SiCl$_4$ ... | (142·1) gas. | 116 | 44? | 6·9 | 302 |
| SiBr$_4$ ... | (91·2) liq. | 92·4 | 44? | 9·8 | 222·4 |
| TiCl$_4$ ... | (181·9) liq. | 116 | ... | ... | ... |
| TiBr$_4$ ... | ... | 92·4 | ... | ... | ... |
| SnCl$_4$ ... | (118·3) gas. | 116 | 74 | ... | 308·3 |
| SnBr$_4$ ... | (92 4) liq. | 92·4 | ,, | 10 | 249 |
| TeCl$_4$ ... | (76·4) crys | 116 | 26·5 | 25 | 196 |
| TeBr$_4$ ... | (66·2) crys. | 92·4 | ,, | 25 | 160 |
| PCl$_5$ ... | (106·2) solid. | 145 | 34·5 | 13·4 | 272·3 |

In the above tables Q in some cases is given for the gaseous state of the compound ; no further correction is required for the latent heat of the compound. The heat of vaporization of Silicon is given as 44 KCal which is obviously too low. The heats

of vaporization of SiBr$_4$, SnBr$_4$, TeBr$_4$ and TeCl$_4$ were calculated approximately, by the application of Trouton's rule from their boiling points given in a previous table. The latent heat of Boron has similarly been approximated by assuming its boiling point to be 3000°C and Trouton's constant as 27. The latent heat of aluminium, belonging to the same group, is 62KCal and the Trouton's constant is 30. The heat of vaporization of Phosphorous includes also the heat of dissociation of the molecule into atoms[4]. The latent heat of PCl$_5$ has been calculated from the vapour pressure data with the help of the relation :—

$$L = R\frac{T_2 T_1}{T_2 - T_1} \log_e \frac{p_2}{p_1}$$

where R is the gas constant, and p$_2$ and p$_1$ are the vapour pressures at the absolute Temperatures T$_2$ and T$_1$ respectively. The logarithm is taken to the base e.

### DISCUSSIONS

In the table 4 are collected the results of the absorption experiments. In another column are tabulated the values of R/n. A study of the table shows that there is a definite departure from the generalised Franck's law in each case and that the departure is greater for the bromides than the corresponding chlorides.

TABLE 4.

| Substance | R$_1$ KCal | R/n KCal | R/R$_1$ | Nature of absorption |
|---|---|---|---|---|
| BCl$_3$ ... | 121 | 86 | 2·12 | sharp does not shift much. |
| BBr$_3$ ... | 103 | 64 | 1·85 | do. |
| SiCl$_4$ ... | 114 | 75·5 | 2·65 | sharp but shifts. |
| SiBr$_4$ ... | 108 | 55·6 | 2·06 | sharp. |
| TiCl$_4$ ... | 87 | ... | ... | do. |
| TiBr$_4$ ... | 76 | ... | ... | do. |
| SnCl$_4$ ... | 84 | 77 | 3·66 | do. |
| SnBr$_4$ ... | 80 | 62 | 3 11 | do. |
| TeCl$_4$ ... | 63 | 49 | 3·09 | Sharp but shifts |
| TeBr$_4$ ... | 62 | 40 | 2·57 | do. |
| PCl$_5$ ... | 69 | 54·4 | 3·95 | Sharp and shifts considerably. |

While in the undisturbed molecule the different halogen atoms may be bound to the metal with equal energy of binding a little greater energy is required to remove any halogen atom optically. This may be due to the fact as has been suggested, that the upper Franck-Condon curve immediately above the normal curve is steep instead of being practically horizontal as assumed for the alkali halides. Hence the energy required to optically dissociate the molecule is appreciably greater than the heat of dissociation obtained thermochemically. Also the sharpness of the beginning of absorption as well as its dependence on temperature will depend on the steepness of the upper curve. As shown in the last column of table 4 there is no much shift in the beginning of absorption for many substance as the pressure (temperature ?) of the vapour is gradually raised. For these we can assume that the upper Franck-Condon curve is more or less horizontal.

The nature of retransmission is not very clear. There is a sharp retransmission in the case of $SnCl_4$ followed by a second absorption. The energy difference between the two beginnings of absorption is 21 kcal which is very much greater than the difference $^2P_{\frac{3}{2}} - {}^2P_{\frac{1}{2}}$ for Cl. In the case of $TiBr_4$ there are two retransmissions each followed by a continuous absorption. Here also there is no agreement between the energy differences of the cuts with those of the excited states of Bromine. It is assumed that the presence of retransmission indicates that there is another Franck-Condon curve above the second curve. Due to the presence of this the transition probabilities from the lower curve (representing the normal state of the molecule) to the first upper curve are modified. It is generally seen that retransmissions are obtained at low pressures.

My best thanks are due to Prof. M. N. Saha for his kind interest in this work.

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# ON THE ABSOLUTE SUMMABILITY (A) OF FOURIER SERIES

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1. The present note is suggested by a memoir of B. N. Prasad which has recently appeared in the Proceedings of the London Mathematical Society, where he has shown, *inter alia*, that if $f(x)$ be a function of bounded variation, the corresponding Fourier series is absolutely summable (A)[1] and has applied his results to the discussion of power series of complex variable[2]. Whittaker[3] has proved that a Fourier series is absolutely summable (A) if

$$\int_0^\delta \left| \frac{\phi(t)}{t} \right| dt$$

exists, where $2\phi(t) = f(\theta + 2t) + f(\theta - 2t) - 2f(\theta)$.

In §2 of this note I prove the absolute summability (A) of Fourier series under de la Vallée-poussin's condition which, as is well-known, includes the conditions of Jordan and Dini under which are proved the two theorems of Prasad and Whittaker referred to above.

In order to get results of a far-reaching character about power series, Prasad has discussed the absolute summability (A) of Young's Restricted Fourier series[4] of the second class. He develops his analysis to show that in the interval of restriction the discussion of the said R. F. series can be reduced to that of the ordinary Fourier

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[1] A series $\sum\limits_{n=0}^{\infty} a_n$,

is said to be *absolutely summable* (A), if

$$f(x) = \sum_{n=0}^{\infty} a_n x^n$$

is convergent in $(0 \leq x < 1)$ and if $f(x)$ is of bounded variation in $(0, 1)$.

[2] Prasad, **2**. See also Prasad, **3**.

[3] Whittaker, **4**.

[4] Young, **5**.

series.  In theorem 2, I show that whatever be the class of the R. F. series, in the interval of restriction it is absolutely summable (A) under the same conditions under which an ordinary Fourier series is so summable.

Finally I indicate that in the light of theorems 1 and 2, more general results for bounded variation of power series of the type of those established by Prasad can be given.

I am much indebted to Dr. B. N. Prasad for his kind interest and advice in the preparation of this paper and also for having allowed me the use of the manuscript of his memoir long before its actual publication.

2.   *Theorem 1.   The Fourier series is absolutely summable* (A) *at a point 0 if a neighbourhood of* $t = 0$ *can be found such that*

$$\frac{1}{t} \int_0^t \phi(u)\ du$$

*is of bounded variation in it.*

We have

$$P(x) = \tfrac{1}{2}a_o + \sum_{n=1}^{\infty} x^n (a_n \cos n\theta + b_n \sin n\theta),$$

$$= \frac{1}{2\pi} \int_{-\pi}^{\pi} f(\alpha) \frac{1-x^2}{1-2x \cos (\theta - \alpha) + x^2}\ d\alpha.$$

Whence,

$$\tfrac{1}{2} Q(x) = \tfrac{1}{2}\pi\{f(x) - f(\theta)\} = \int_0^{\frac{1}{2}\pi} \phi(t)\ \frac{1-x^2}{1-2x \cos 2t + x^2}\ dt,$$

$$= \left( \int_0^{\delta} + \int_{\delta}^{\frac{\pi}{2}} \right) \phi(t)\ \frac{1-x^2}{1-2x \cos 2t + x^2}\ dt,$$

$$= Q_1(x) + Q_2(x),$$

where  $\delta$  is a positive number such that $0 < \delta < \frac{\pi}{2}$ and is so chosen that

$$\frac{1}{t} \int_0^t \phi(u)du$$

is of bounded variation in (0, $\delta$).

As $Q_2(x)$ is of bounded variation in $(0, 1)$, we have simply to show that $Q_1(x)$ is so.

Let

$$\Phi(t) = \frac{1}{t} \int_0^t \phi(t)\, dt.$$

Then

$$\Phi'(t) = \frac{\phi - \Phi}{t},$$

except at most for a set of points of measure zero.

Now

$$Q_1\ (x) = \int_0^\delta \phi(t)\ \frac{1-x^2}{1-2x\cos 2t + x^2} dt$$

$$= \int_0^\delta \Phi\ (t)\frac{1-x^2}{1-2x\ \cos\ 2t+x^2}\ dt + \int_0^\delta t\Phi'\ (t)\frac{1-x^2}{1-2x\ \cos\ 2t + x^2} dt,$$

$$= R_1\ (x) + R_2(x).$$

Since $\Phi(t)$ is, by hypothesis, of bounded variation in $(o, \delta)$, $R_1(x)$ is of bounded variation in $(o, 1)$ by Prasad's criterion[5]; also since $\Phi(t)$ is of bounded variation, $t\Phi'(t)$ satisfies Dini's condition. Hence by Whittaker's criterion[6], $R_2(x)$ is of bounded variation in $(o, 1)$. Therefore $Q_1(x)$ and consequently $Q(x)$ is of bounded variation in $(o, 1)$. This proves the theorem[7].

3. *Theorem 2. The R. F. series of pth class will be absolutely summable* (A) *at every point in the interval of restriction at which any of the conditions sufficient for the absolute summability* (A) *of a Fourier series is satisfied.*

Let

$$V = \frac{1-x^2}{1-2x\ \cos\ (\theta - u) + x^2}.$$

It is easily seen that

$$\frac{\delta^p\ V}{\delta\theta^p} = (1-x^2)\ \sum_{k=0}^{p-1} \frac{x^{p-k}T_k\ (\theta)}{[1-2x\cos\ (\theta - u) + x^2]^{1+p-k}},$$

where $T_k(\theta)$ is a polynomial in $\sin (\theta - u)$ and $\cos (\theta - u)$,

so that $\qquad |\Gamma_k(\theta)| < A$ (a constant).

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[5] Prasad 2, loc. cit., 411.

[6] Whittaker, loc. cit., 2.

[7] I learn from Dr. B. N. Prasad that in a manuscript sent to him by Dr. Bosanquet, the latter has proved a more general theorem of this character.

Hence, $\left|\dfrac{\delta^p V}{\delta\theta^p}\right| \leq A(1-x^2)\sum\limits_{k=0}^{p-1}\dfrac{x^{p-k}}{(1-x)^{2(1+p-k)}}$,

which shows that $\dfrac{\delta^p V}{\delta\theta^p}$ is bounded for $-\delta < u < \delta$, $a < \theta < \beta$,

and $o \leq x < 1$, $p$ being a positive integer.

Now let $f(\theta)$ be the function associated with the R. F. series of $p$-th class.

$$f(\theta) \sim \sum_{n=1}^{\infty} (a_n \cos n\theta + b_n \sin n\theta),$$

the interval of restriction being $(a, \beta)$, and let us suppose that $a_n$ and $b_n$ are bounded or in particular tend to zero as $n \to \infty$. Further let the $p$th integrated series, which is necessarily a Fourier series, converge to $F(\theta)$ which is a $p$th integral. Then

$$f(\theta) = \frac{d^p F}{d\theta^p},$$

and is defined almost everywhere in $(a, \beta)$.

Since the $p$th integrated series is a Fourier series of $F(\theta)$, we heve *either*,

$$a_n = \pm \frac{n^p}{\pi} \int_{-\pi}^{\pi} F(u) \cos nu \, du,$$

$$b_n = \pm \frac{n^p}{\pi} \int_{-\pi}^{\pi} F(u) \sin nu \, du,$$

according as $p = 4k$ or $4k+2$ where $k = 0, 1, 2, 3, \ldots\ldots\ldots$,

*or*,

$$a_n = \pm \frac{n^p}{\pi} \int_{-\pi}^{\pi} F(u) \sin nu \, du,$$

$$b_n = \pm \frac{n^p}{\pi} \int_{-\pi}^{\pi} F(u) \cos nu \, du,$$

according as $p = 4k+1$ or $4k-1$.

Whatever be $p$, we have,

$$\pi P(x) = \pi \sum_{n=1}^{\infty} x^n(a_n \cos n\,\theta + b_n \sin n\,\theta)$$

$$= \sum_{n=1}^{\infty} x^n \int_{-\pi}^{\pi} F(u) \frac{\delta^p}{\delta\theta^p} \cos n\,(\theta - u) \, du,$$

$$= \int_{-\pi}^{\pi} F(u) \frac{\delta^p}{\delta\theta^p} \frac{1-x^2}{1-2x\cos(\theta-u)+x^2} du,$$

$$= \left( \int_{-\pi}^{-\delta} + \int_{\delta}^{\pi} + \int_{-\delta}^{\delta} \right) F(u) \frac{1-x^2}{1-2x\cos(\theta-u)+x^2} du,$$

$$= P_1 + P_2 + P_3.$$

It is seen easily that $P_1$ and $P_2$ are of bounded variation in $(0, 1)$. Also

$$\pi P_3 = \int_{-\delta}^{\delta} F(u) \frac{\delta^p}{\delta\theta^p} \frac{1-x^2}{1-2x\cos(\theta-u)+x^2} du,$$

$$= \frac{\delta^p}{\delta\theta^p} \int_{-\delta}^{\delta} F(u) \frac{1-x^2}{1-2x\cos(\theta-u)+x^2} du,$$

the differentiation under the integral sign being justified as V is bounded[8].

*Or,*

$$\pi P_3 = \frac{\delta^p}{\delta\theta^p} \int_0^{\delta} \{F(\theta+t)+F(\theta-t)\} \frac{1-x^2}{1-2x\cos t + x^2} dt.$$

Now if we choose $\delta$ such that the interval $(\theta-\delta, \theta+\delta)$ lies wholly within the interval of restriction $(\alpha, \beta)$, $\{F(\theta+t)+F(\theta-t)\}$ is a $p$th integral in $(\theta, \delta)$. Also $\frac{1-x^2}{1-2x\cos t+x^2}$ is an integral. Hence differentiating[9] $p$ times under the integral sign, we have

$$\pi P_3 = \int_0^{\delta} \{f(\theta+t)+f(\theta-t)\} \frac{1-x^2}{1-2x\cos t+x^2} dt,$$

$$= \int_0^{\delta} \chi(t) \frac{1-x^2}{1-2x\cos t+x^2} dt,$$

where $\chi(t) = f(\theta+t)+f(\theta-t)$, which shows that $P_3$ and consequently $P$ is of bounded variation in $(0, 1)$ if $\chi(t)$ or $f(\theta)$ satisfies any of the conditions for the absolute summability (A) of Fourier series. This proves the theorem.

4. Following Prasad's memoir referred to above, we easily get the following theorem on the bounded variation of power series, the radius of the circle of convergence being unity.

[8] Hobson, 1, 356.

[9] ibid, 361,

THEOREM 3.　*If a power series* $\sum\limits_{n=1}^{\infty} c_n x^n$ *with bounded coefficients, is such that its second integrated series, which necessarily converges uniformly on the circle of convergence, has for sum a function* $F(\theta)$ *whose second differential coefficient is such that*

$$\frac{1}{t}\{F'(\theta + t) - F'(\theta - t)\}$$

*is of bounded variation for all points of an arc, then the power series is a function of bounded variation on every radius vector in that arc.*

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# ON NEW TREMATODES OF FROGS AND FISHES OF THE UNITED PROVINCES, INDIA

**Part II.**—"Three New Trematodes of the Sub-family Pleurogenetinæ (Family Lecithodendriidæ) from Rana cyanophlyctis of Oudh.".

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## Genus Prosotocus. Looss 1899.

This genus was errected by Looss in 1899 for the reception of *Distomum confusum* Lss 1894 and *Distomum tener* Lss 1898. The former is a common parasite in the intestine of European frogs while the latter is found in the gut of *Chamaeleo basiliscus* in Egypt. Dujardin in an earlier paper published in 1845 described *Dist. confusum* under the name *Dist. (Brachycœlium) clavigerum*. Pagenstecher 1897 also refers to the same worm as *Dist. clavigerum*. It appears that both Dujardin and Pagenstecher were unaware of the existence of Rudolphi's *Dist. clavigerum* 1819 (Pleurogenes claviger). In 1905 Stafford following Looss included both *Dist. confusum* and *Dist. tener* under *Prosotocus*. In the same year Klein, however, tentatively referred both of them to the genus *Pleurogenes* in his key, although he sharply separated *Pleurogenes confusum* from all the other species owing to the anterior position of the testes, *i.e.* in front of the cirrus sac. In 1909 Luhe again reverted to the original classification and maintained the genus *Prosotocus* assigning *Pleurogenes confusus* to it. All the subsequent workers, Travassos, Nicoll, Mehra and Negi and Modlinger have maintained *Dist. confusum* and *Dist. tener* as belonging to *Prosotocus* and *Pleurogenes* respectively.

Till now the genus contains seven species. Besides the type species *Pr. confusum* Lss 1894 Mehra and Negi in 1928 added a new species *Pr. indicus* from *Rana tigrina* (India). In 1930 Travassos while going through the original account of *Dist. confusum* Lss. 1894 found that figs 33 pl. 2. p 101 and 35 pl. 8, p. 164 represented two distinct species, of which the latter he described as a new species, *Pr.*

*fuelleborni* and pointed out its identity with *Pr. confusum* Braun 1915 p. 154, fig. 126 and *Pr. confusum* Fuhrmann 1928 p. 75 fig, 97. Modlinger in 1930 has added four more new species to the genus.

In the following pages I give an account of one more new species belonging to the genus.

### Prosotocus infrequentum n. sp.

Fig. 1

Host—*Rana cyanophlyctis.*
Habitat—Duodenum.
Locality—Sitapur, Oudh (India).

This species was met with in the duodenum of only two out of more than one hundred frogs examined. In the living condition the parasite has a minute spherical shape with a light brown colour. The part of the body in front of the acetabulum is very mobile while the part behind it has little power of contraction and expansion. When fixed under a slight pressure of a coverglass the parasite assumes an elliptical shape and measures 1'10 mm. in length and 0'5 mm. in maximum breadth which lies across the acetabular region. The body is covered all over with minute backwardly directed spines of 0'005 mm. length which occur in large number in the anterior part and become gradually sparse towards the posterior end.

The oral sucker is subterminal and ventrally directed, with a spherical outline, measuring 0'10 mm. in diameter. The acetabulum is shallow and poorly muscular, situated about the middle of the body and measuring 0'14 mm. in diameter. The size ratio of the oral and ventral suckers is as 5 : 7.

The genital atrium is a shallow depression on the ventral body surface situated about half way between the level of the left testis and the left body margin, anterior to the left testis and in level with the middle or anterior third of the oesophagus. The male and the female openings lie in the genital atrium 0'06 mm. apart ; the female opening lies a little cephalad and nearer the median line.

The excretory pore lies at the extreme posterior end of the body.

The oral sucker leads posteriorly into a small spherical pharynx, measuring 0'06 mm. in diameter. It is followed by a fairly long oesophagus of 0'15 mm. length and 0'02 mm. width. The intestinal bifurcation lies near the end of the anterior one-fourth body length. The cæca are short and diverge considerably apart terminating near the middle or the anterior one-third part of the acetabulum.

The testes are nearly spherical, situated asymmetrically one on either side of the intestinal fork and the cæca between the latter and the body wall. The left

testis, 0·13 × 0·12 mm. is smaller than the right testis and lies a little in front of the latter close to the median line. The right testis 0·14 mm. in diameter lies near the right body wall. The vasa efferentia are small thin tubes which arise from the inner posterior margins of the testes. They meet near the middle of the left cæcum to form an inconspicuous vas deferens which enters the cirrus sac to continue into the vesicula seminalis. The cirrus sac is strongly developed and large in proportion to the size of the body, measuring 0·35 mm. in length and 0·1 mm. in maximum breadth. It consists of a swollen cone shaped proximal part, 0·2 mm. long which lies obliquely behind the left testis and extends ventrally to the left intestinal cæcum ; and a distal portion of a narrower tubular form, 0·15 mm. in length and running parallel to the left body margin. The angle of curvature between these two parts lies in level with the intestinal bifurcation. The vesicula seminalis is coiled with a swollen base and opens into a small oval pars prostatica of 0·05 mm. length and 0·15 mm. breadth. The ductus ejaculatorius, 0·15 mm. in length is a narrow straight tube running more or less parallel to the length of the distal part of the cirrus sac and passes terminally into a small cirrus. The entire space between the coiled vesicula seminalis, the pars prostatica and the walls of the cirrus sac is closely packed with deeply staining prostate cells with prominent nuclei.

The ovary is pearshaped and very much smaller than the testes, measuring 0·08 mm. in diameter and lies slightly in front of the acetabulum to the right of the median line, partially overlapped by the intestinal cæcum. It gives off from its inner margin a short oviduct which soon dilates to form the ootype surrounded by diffuse shell gland cells. The receptaculum seminis is a small elongated sac, situated to the right side close to and partly overlapped by the acetabulum. A short Laurer's canal arises from the neck of the receptaculum seminis.

The vitellaria are poorly developed and are confined to the ventral surface where they are disposed in the form of small indistinct diffuse follicles, scattered more or less laterally between the oral sucker, the intestinal cæca and the bodywall. The vitelline ducts run obliquely and meet to form a small triangular yolk reservoir which lies to the right side of the anterior half of the acetabulum.

The uterus arises from the shell gland mass to the right side of the acetabulum and the receptaculum seminalis and passes downwards in a zigzag course with the windings arranged mainly longitudinally in the right and left halves of the body extending upto the hinder end. The convolutions extend a little in front of the acetabulum but never reach the intestinal bifurcation. The longitudinally disposed convolutions are joined by a horizontal connection a little in front of the middle of the postacetabular region. The terminal part of the uterus is more or less straight and runs parallel to the cirrus sac. The metraterm is small and thick-walled measuring 0·088 × 0·025 mm. in size. It lies internally to the terminal part of the

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cirrus sac and extends slightly cephalad of the latter. The ova, 0·033 × 0·013 mm. are elliptical in shape and light brown in colour.

The excretory bladder is V-shaped with a small median stem of 0·19 mm. length. The cornua of the bladder extend upto the posterior margin of the acetabulum. The excretory pore is terminal.

In its relationship *Prosotocus infrequentum* n. sp. stands nearest to *Pr. indicus*, resembling the latter in the shape of its body, position of the gonads, arrangement of the uterine convolutions and the shape of the excretory bladder. In the size of its ova it resembles *Pr. confusus*. This species is, however, characterised by the acetabulum being larger than the oral sucker, position of the genital atrium a little away from the left body margin with the male and female pores situated apart from each other, position of the receptaculum seminis to the left side of the commencement of the uterus, large size of eggs and the terminal position of the excretory pore.

## Genus Ganeo Klein 1905.

In 1905 Klein described the type species of this genus under the name *G. glottoides,* obtained from a frog—*Rana hexadactyla* from Madras (India). Though he was not definite about the systematic position of the genus, he placed it tentatively under *Pleurogenetinae* Looss 1899. Odhner in 1911 discussed its systematic position assigning it to the subfamily *Pleurogenetinae* in the family *Lecithodendriidae.* Scrjabin in 1922 described *G. glottoides var. africana* from amongst the parasitic nematodes and trematodes collected by the expedition of Prof. Dogiel and Sokolov in British East Africa. In 1926 Bhalerao reported the existence of *G glottoides* in the common Indian frog—*R tigrina.* Two years later Mehra and Negi described a new species, *G. tigrinum* and a new variety *G glottoides var. madrasensis,* from the same host species belonging to two different and far apart localities in India. While considering the genus *Ganeo* to be aberrant they agreed with Odhner in including it definitely in the above mentioned subfamily. According to the scheme of classification given by Fuhrmann in Kukenthal and Krumback's Handbuch der Zoologie, Berlin, 1928, the genus is retained under the *Plaerogenetinae.* Travassos, however, in 1930 has placed it in the subfamily *Lecithodendriinae* on the basis of its copulatory apparatus. In view of the resemblance shown by this genus in most of its characters with the *Pleurogenetinae* the author considers Travassos's position untenable and accepts the position assigned to it by Odhner, Mehra and Negi and Fuhrmann.

## Ganeo gastricus n. sp.

Fig. 2.

Host—*Rana cyanophlyctis*.

Habitat—Stomach.

Locality—Sitapur, Oudh (India).

This species is represented by a single specimen in my collection of trematodes from *Rana cyanophlyctis*. It was found attached to the wall of the stomach together with several specimens of *Halipegus mehransis* Srivastava 1933. The body is flattened and oval, tapering anteriorly and broadly rounded posteriorly, with a small conical projection on the left body margin at the level of the intestinal bifurcation. The slightly pressed specimen measures 3˙65 mm. in length and 1˙6 mm. in maximum breadth, which lies halfway between the ends of the intestinal cæca and the posterior body end. Large number of small backwardly directed spines are present on the body surface upto the intestinal bifurcation, behind which they rapidly decrease in number and finally in the postacetabular region disappear altogether. The oral sucker is terminal and anteriorly directed. The acetabulum, situated at a little behind the first third body length, is oval in shape with its long axis directed nearly parallel to the length of the body. The transverse diameter ratio of the oral and ventral suckers is 4 : 5.

The mouth, situated at the bottom of the oral sucker, leads through an inconspicuous prepharynx into an oval and muscular pharynx, measuring 0˙125 × 0˙1 mm. The oesophagus, 0˙4 mm. long bifurcates into the intestinal cæca at the anterior one sixth body length. The cæca are of equal length and run close to the lateral body margin terminating in front of the posterior ⅔th part of the body length.

The testes are more or less ovoid and compact in structure lying a little obliquely one on each side of the median line. Transversely they are separated from each other by a distance of 0˙38 mm. and lie partly covering the intestinal cæca. The right testis measuring 0˙35 × 0˙24 mm. lies at 0˙93 mm. distance from the anterior end. The left testis, 0˙3 × 0˙24 mm. is situated at a distance of 1˙10 mm. from the anterior end being shifted more posteriad on account of the pars prostatica and vesicula seminalis which lie on the same side. The vesicula seminalis is fairly long and coiled and commences near the median line in level with the anterior margin of the left testis. Anteriorly it passes by a small narrow duct into a moderately long pars prostatica 0˙4 mm. in length and 0˙1 mm. in maximum breadth. A large number of conical prostatic cells open into the pars prostatica. A small

ductus ejaculatorius, 0˙26 × 0˙05 mm., is present and opens ventrally at the anterior corner of the genital atrium. The latter lies on a short conical projection of the left body margin in level with the region of the intestinal bifurcation.

The ovary is almost spherical, 0˙26 × 0˙27 mm. in diameter and lies to the right side near the right testis between the intestinal cæcum of that side and the acetabulum. The oviduct arises from its left margin and soon receives the duct of the receptaculum seminis. The latter is of large size and has an inverted comma shaped outline, measuring 0˙35 × 0˙21 mm. It is situated behind the ventral sucker with its neck bent towards the right side. A fairly broad Laurer's canal 0˙01 mm. arises from the neck of the receptaculum seminis. The transverse vitelline ducts open into a prominent yolk reservoir situated near the median line close behind the ventral sucker. The ootype as usual is surrounded by diffuse shell gland cells.

The vitellaria lie laterally in the body confined to the ventral surface of the intestinal cæca, extending from the body margin to half way between the intestinal cæca and the median line. They occupy about $^2/_7$th part of the body length and are composed of numerous pear-shaped follicles with their ends directed mesially. They do not begin at the same level ; the right gland of 1˙0 mm. length commences a little in front of the left one, i.e., from the anterior margin of the acetablum and the left gland 0.95 mm. in length, begins a little behind, i.e., from the posterior margin of the latter.

The uterus is enormously developed and composed of numerous transverse convolutions which partly overlap one another, reaching the extreme hinder end. Laterally the uterine coils overlap the intestinal cæca at a few places till the posterior extremity of the vitellaria ; but in the post-vitellarian region they extend outwards filling the entire space as far as the body margin. The terminal part of the uterus passes anteriorly to the left side of the receptaculum seminis and the acetabulum in a zigzag course to open into the genital atrium. The whole uterus is stuffed with numerous small operculate ova of golden yellow to dark brown colour, measuring 0˙023 × 0˙013 mm. in size.

The excretory bladder is U-shaped with no median stem. The excretory opening is situated subterminally on the ventral surface.

In its affinities the parasite stands nearest to *Ganeo tigrinum* Mehra and Negi 1928 with which it agrees in the shape of its body and absence of a pseudocirrus sac, but it differs in the following important features :—

Oral sucker terminal ; acetabulum oval, situated a little behind the anterior one-third bodylength as in the type species ; transverse diameter of oral to ventral sucker 4 : 5. Intestinal cæca are a little longer and run closer to the body margin than in *G. tigrinum*. Testes situated somewhat obliquely, one on each side of

median line, overlapping intestinal cæca. Ovary spherical to the right side contiguous with anterior testis in the space between right intestinal cæcum and acetabulum. Vitellaria of greater length. Genital pore situated on a conical projection of the left body margin in level with the intestinal bifurcation. Characteristic arrangement and extent of the uterine coils, ova smaller. Excretory bladder without a main stem.

Habitat — Stomach of *Rana cyanophlyctis*.

## Ganeo attenuatum n. sp.

### Fig. 3.

Host—*Rana cyanophlyctis*.

Habitat—Intestine.

Locality—Sitapur, Oudh (India).

Of all the trematodes found in *Rana cyanophlyctis* this species stands first in the intensity of infection ; in its frequency of occurrence it comes second to *Halipegus mehransis* Srivastava 1933. The distomes were met with in varying numbers of 7—95 in eight out of every ten frogs examined. They show considerable power of contraction and expansion ; in the intestine of the host they were found moving about freely by expanding and contracting their bodies in different planes. An attempt was made to keep them alive at the laboratory temperature in various nutritive solutions, changed every day and the results are given in Table I :—

### TABLE I

Date 2nd—6th August 1932. Laboratory temperature 79°—82·5°F.

| Nutritive solutions used. | Physiological salt solution 0·75% | Phys. salt solution and yolk 1 : 2 | Phys. salt solution and albumen 1 : 1 | Phys. salt sol. and yolk and albumen 1 : 2 : 2 | Sugar solution 5% |
|---|---|---|---|---|---|
| Number of parasites kept ... | 5 | 5 | 5 | 5 | 5 |
| Maximum number of hours they lived ... | 18 | 50 | 42 | 68 | 20 |
| Number of parasites lived for maximum period ... | 3 | 4 | 3 | 4 | 2 |

This species is less susceptible to varying conditions of diet and temperature and is, therefore, more tenacious of life than *G. tigrinum* Mehra and Negi 1928. In summer (79°—82'5°F) the parasites could live for 68 hours in a mixture of one part of physiological salt solution to two parts each of yolk and egg albumen.

In the living condition the parasites are light grey in colour and vary from 1'2—4'4 mm. in length. They are thin and transparent with a flat attenuated body, bluntly pointed at both ends. Slightly pressed specimens in permanent mounts measure 2'4 – 3'4 mm. in length and 0'5—0'8 mm. in breadth at the level of the posterior end of the vitellaria, 0'57—0'75 mm. at that of the anterior end of the vitellaria and 0'56—0'67 mm. at that of the genital opening. The cuticle is thickly studded with small triangular spines of 0'007 × 0'0012 mm. size in the preacetabular region. Behind the acetabulum they, however, gradually decrease in number and finally disappear near the blind extremities of the intestinal cæca. The spines on the ventral surface are slightly larger than those elsewhere.

The subterminal oral sucker is transversely oval with its transverse and longitudinal diameters measuring 0'144 and 0'128 mm. *i.e.* in the ratio of 9 : 8. The acetabulum may occupy, according to the degree of contraction, any position between the anterior third and first half of the body. It is slightly oval in outline, with its long axis parallel to the length of the body measuring 0'16 × 0'144 or 0'176 × 0'16 mm. i.e. in the ratio of 10 : 9, The oral and ventral suckers are nearly equal in size ; their transverse and longitudinal diameters are in the ratio of 1 : 1 and 4 : 5 respectively.

The genital atrium is fairly deep and opens to the outside on the left body margin in level with the middle of the oesophagus. The excretory pore lies on the ventral surface just in front of the posterior end of the body.

The mouth is situated at the bottom of the ventrally directed oral sucker. Posteriorly it opens into a distinct thin walled prepharynx measuring 0'075 – 0'1 mm. in length. It is followed by a thick-walled globular pharynx of 0'07 – 0'09 × 0'11 mm. dimensions. The oesophagus is a fairly long narrow tube of 0'3 – 0'5 mm. length and bifurcates a little in front of the anterior testis, at about the anterior one-fifth body length. The blind extremities of the intestinal cæca terminate in front of the posterior one-third or one fourth body length.

The testes are intracæcal, situated obliquely behind each other in the space between the intestinal bifurcation and the posterior margin of the acetabulum. They are usually spherical or slightly ovoid in outline and only exceptionally have an irregularly crenated margin. The anterior testis of 0'16 – 0'25 × 0'17 – 0'22 mm. size is

situated in the median line or slightly to the right side, much in front of the acetabulum just behind the intestinal bifurcation. The posterior testis, 0'17 − 0'24 × 0'19 − 0'2 mm. in size lies behind to the right side in the space between the right intestinal cæcum and the acetabulum. The vas efferens of the anterior testis arises as a small delicate tube from its posterior margin nearer the right side and runs backwards to join the much smaller vas efferens of the posterior testis. The vas deferens is small and inconspicuous. The vesicula seminalis is a small thin-walled tube coiled in the form of a characteristic loop and filled with sperms. It is continued anteriorly into a small narrow tube which opens into the pars prostatica. The pars prostatica is a swollen elongated tube of 0'26 mm. length and 0'05 mm. breadth and is surrounded by a huge mass of diffuse prostate gland cells. It leads distally into the ductus ejaculatorius of 0'16 − 0'24 mm. length. An eversible cirrus is absent. A true cirrus sac is absent.

The ovary, 0'1 − 0'14 × 0'13 − 0'17 mm. in size is small, usually spherical or pear-shaped in outline and lies to the right side close behind the acetabulum. Only occasionally it has a heart-shaped outline with its apex extending between the posterior third of the ventral sucker and the posterior testis. The short oviduct arises from the inner margin of the ovary. The receptaculum seminis is well developed and is flask shaped, measuring 0'12 − 0'14 × 0'05 − 0'1 mm in size and is situated just behind the ovary to the right side with a transversely bent neck directed towards the median line, immediately behind the ovary. The Laurer's canal, 0'012 mm. wide, arises from the neck of the receptaculum seminis. The yolk reservoir is situated in the angle between the flask-shaped receptaculum seminis and its bent neck. The shell glands form a diffuse mass near the median line behind the ovary. The vitellaria lie laterally, beginning a little behind the ventral sucker or in level with the posterior margin of the ovary and terminating near the commencement of the posterior half or posterior third bodylength. They consist of small follicles, closely situated together ventrally and laterally to the intestinal cæca, extending from the body margin to a small distance inward of the latter. The right vitelline gland of 0'43 − 0'66 mm. length is usually larger than the left one which measures from 0'46 − 0'67 mm. in length.

The testes, ovary and the vitellaria appear to disintegrate after a large number of eggs has been produced, though the parasite continues to live for a fairly long time. One mature individual with its gonads in a degenerate condition lived for 68 hours in the nutritive solution at a temperature of 79°—82'5°F as mentioned in the table.

The windings of the uterus are not so numerous and intricately coiled as in the other species of the genus. They are small, transversely arranged and never

overlap the intestinal caeca. The descending coils lie dorsal to the ascending coils. The terminal part of the ascending uterus passes first between the acetabulum and the left intestinal cæcum and then between the latter and the vesicula seminalis to meet the muscular metraterm of 0˙25 mm. length and 0˙035 mm. breadth. The metraterm lies ventral and to the right side of the ductus ejaculatorius. Towards the hinder end the uterus stops short of the bifurcation of the median stem of the excretory bladder. The ova are operculate and elliptical with light brown colour, measuring 0˙03 × 0˙015 mm. in size.

The excretory bladder is V-shaped with very long cornua extending upto the acetabulum and a small median stem of 0˙2 mm. length. The excretory pore lies on the ventral side close to the posterior end.

This species differs from *Ganeo glottoides*, *G. glottoides* var *africana* and *G. glottoides* var *madrasensis* in the absence of a pseudocirrus sac, topography of the genital glands, position of excretory opening and position, shape and size of suckers. It resembles *G. tigrinum* in the absence of a pseudocirrus sac, position of the testes, form of the excretory bladder and the position of its excretory opening. But it differs from the latter in the characteristic attenuated shape of its body, position, shape and size of suckers, shape of its receptaculnm seminis, peculiar shape of its vesicula seminis, length of vitellaria, configuration of the uterine coils and the shape of its eggs. *Ganeo attenuatum* has been met along with *G. gastricus* in the same host and it resembles the latter species in the absence of a pseudocirrus sac and shape of its suckers but it differs in the shape of its body, position and size of suckers, form of excretory bladder, extent of vitellaria and the configuration and extent of uterus. *G. attenuatum* differs remarkably from all the known species of the genus in possessing a muscular metraterm.

The description of the two new species necessitates a certain amount of modification in the diagnosis of the genus *Ganeo* as given by Mehra and Negi 1928. The emended diagnosis of the genus is as follows :

Small or medium sized distomes ; body elongated and tongue-shaped, elliptical attenuated, oval or oblong ; cuticle partly or wholly covered with small spines. Acetabulum situated at the junction of anterior middle thirds or between anterior third and half of body ; oesophagus short or moderately long ; intestinal cæca equal or unequal extending about or beyond ⅔ths of body but never reaching the hind end. Genital opening or openings situated ventrally near left border in anterior part about middle of oesophagus or in neighbourhood of intestinal bifurcation ; genital atrium well developed. Testes in posterior part of anterior third or half of body obliquely situated behind each other or parallel one on each side ;

their position in regard to acetabulum variable. Ovary post-testicular, in or infront of middle half of body. Vitellaria situated laterally, ventral to intestinal cæca for a considerable length. True or muscular cirrus sac absent, pseudo-cirrus sac present or absent ; uterine convolutions transversely arranged behind the acetabulum in the intracæcal zone or extending laterally over or beyond the intestinal cæca. Metraterm absent or present ; eggs oval or elliptical measuring $0\cdot023 - 0\cdot034 \times 0\cdot013 - 0\cdot018$ mm. Excretory bladder U or V-shaped, with or without a short median stem ; excretory pore terminal or subterminal.

Habitat—Stomach and intestine of Amphibia.

Distribution—India and Africa.

## Systematic discussion on the Genus Ganeo Klein 1905.

Odhner 1911, Mehra and Negi 1928 and Fuhrmann 1928 are all agreed in assigning the genus *Ganeo* to the subfamily *Pleurogenetinae* Looss 1899. Travassos in 1930, however, has transferred the genus to the subfamily *Lecithodendriinæ* Odh. on the basis of the copulatory apparatus. In their systematic discussion on the genus Mehra and Negi in 1928 mentioned four important points in which the genus differs from the *Pleurogenetinæ*, *i. e.* absence of a true muscular cirrus sac, position of the vitellaria, shape of the excretory bladder and the absence of a metraterm.

The arrangement of the testes with regard to one another varies remarkably in different species and even in different varieties. Undoubtedly their oblique position behind each other in some forms is somewhat untypical for the subfamily *Pleurogenetinæ*, but it is by no means peculiar to this genus only, for even in *Pleurogenes loossi* Africa 1930 the testes lie obliquely behind each other. Their position, one on each side of the body as known in *G. glottoides* var. *madrasensis* and *G. gastricus* n. sp., represents the primitive condition characteristic of the genus *Pleurogenes*.

In view of the recently known forms such as *Cryptotropa kurantanii*, *Pleurogenes lobatus* and a specimen of *Pleurogenes claviger* studied and figured by Travassos (Fig. 1 Travassos 1931) in which the vitellaria extend behind the acetabulum and occupy lateral positions or lie scattered all over the body, the position of the vitellaria in the genus *Ganeo* does not show much departure from that existing in some members of the *Pleurogenetinæ*.

In the species reported hitherto the excretory bladder is U-shaped and a metraterm is absent. In *G. attenuatum* n. sp. both a V-shaped excretory bladder and a

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metraterm are present.   There is only one distinctive feature left which distinguishes *Ganeo* from all the genera of the *Pleurogenetinæ* and brings it closer to such genera as *Lecithodendrium*, *Prosthodendrium* and *Pycnoporus* etc., *i.e.*, the absence of a true muscular cirrus sac.   But as the genus differs remarkably in the totality of its organisation from the *Lecithodendriinæ*, the absence of a cirrus sac is not a strong argument to warrant the transference of the genus from the *Pleurogenetinæ* to the *Lecithodendriinæ*, especially when it shows the characteristic Pleurogenetine characters such as the position of the genital pore near the left border in the anterior part of the body, ovary near the acetabulum to the right side or near the median line, twisted vesicula seminalis, well developed pars prostatica and prostate gland cells, the arrangement of uterine coils, the presence of a metraterm, the V-shaped excretory bladder, the habitat and host.

## Key to the species and varieties of the Genus Ganeo Klein 1905

1.  Metraterm present   .   .   .   .   .   .   . *G attenuatum* n. sp.
    Metraterm absent   .   .   .   .   .   .   . 2
2.  Pseudocirrus sac present   .   .   .   .   . 3
    Pseudocirrus sac absent   .   .   .   .   . 5
3.  Pseudocirrus sac strongly curved, oesophagus small   *G. glottoides* var
                                                            *madrasensis.*

    Pseudocirrus sac straight or slightly curved, oeso-
        phagus moderately long   .   .   .   .   . 4
4.  Intestinal cæca extend to $^3/_5$th body   .   .   . *G. glottoides.*
    Cæca reach near the hind end .   .   .   .   . *G. glottoides* var
                                                       *africana*
5.  Excretory bladder with a median stem   .   .   . *G. tigrinum*
    Excretory bladder without a median stem   .   . *G. gastricus* n. sp.

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## EXPLANATION OF PLATES

Fig. 1.  Ventral view of *Prosotocus infrequentum* n. sp.

Fig. 2.  Dorsal view of *Ganeo gastricus* n. sp.

Fig. 3.  Ventral view of *Ganeo attenuatum* n. sp.

## LETTERING

| | | | | | |
|---|---|---|---|---|---|
| Act. | ... | Acetabulum | Oes. | ... | Oesophagus |
| C. | ... | Cirrus | Oot. | ... | Ootype |
| D. ej | ... | Ductus ejaculatorius | O. s. | ... | Oral sucker |
| E. bl. | ... | Excretory bladder | Ph. | ... | Pharynx |
| E. bl. c. | ... | Excretory bladder cornua | P. p. | ... | Pars prostatica |
| Eg. | ... | Egg | Pr. gl. | ... | Prostate glands |
| E. p. | ... | Excretory pore | R. sm. | ... | Receptaculum seminis |
| G. a. | ... | Genital atrium | T. | ... | Testis |
| G. p. | ... | Genital pore | Ut. | ... | Uterus |
| I. c. | ... | Intestinal cæca | V. sm. | ... | Vesicula seminalis |
| L. c. | ... | Laurer's canal | Vit. | ... | Vitellaria |
| Mtm. | ... | Metraterm | Y. r. | ... | Yolk reservoir |
| Ov. | ... | Ovary | | | |
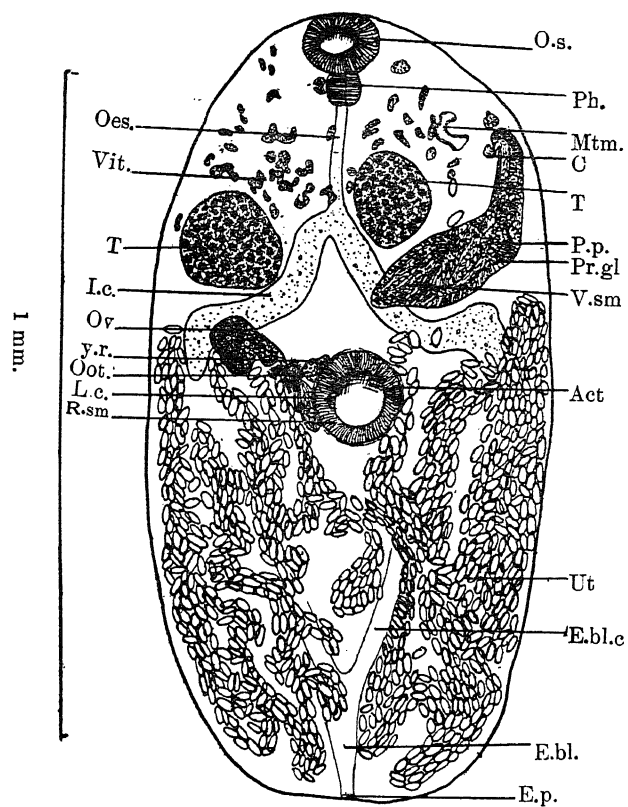
FIG. 1.
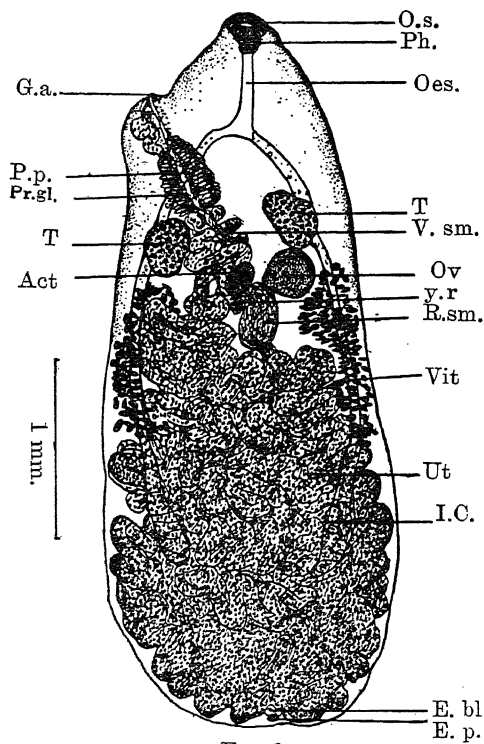
FIG. 2
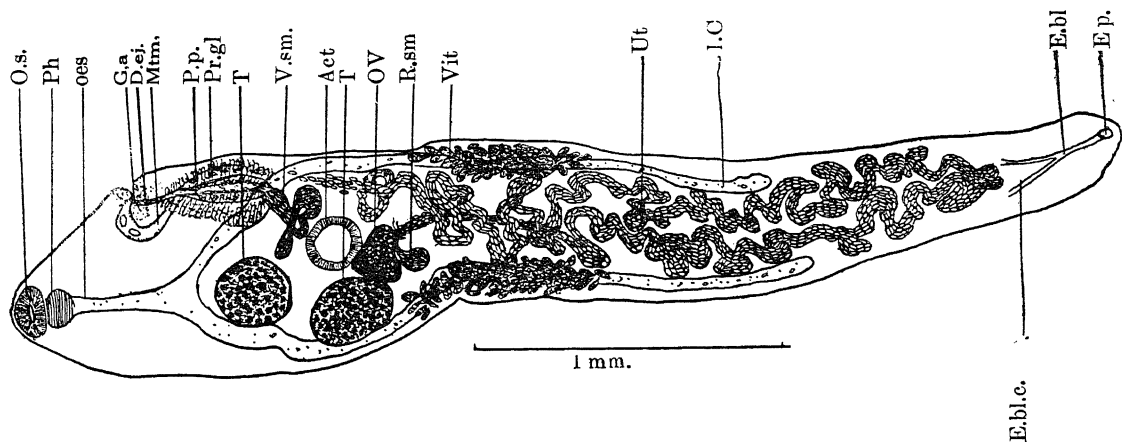
FIG. 3.

# ON A NEW TREMATODE WITH ANUS BELONGING TO THE GENUS OPEGASTER OZAKI 1928, FROM AN INDIAN EEL ANGUILLA BENGALENSIS

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## Introduction

The family Opecœlidæ Ozaki 1925, is exclusively parasitic in the digestive tract of fishes. It includes three genera, *Opecœlus* Ozaki 1925, *Opegaster* Ozaki 1928, and *Anisoporus* Ozaki 1928. The new form described in this paper is the fourth species of the genus *Opegaster* which includes till now three species, *Opegaster ovatus, O. rectus, O. brevifistula*, all described by Ozaki in 1928 from Japan. *Opegaster anguillii* n. sp. was found in the fresh water eel, *Anguilla bengalensis* Gray and Hardw, caught from the river Jumna at Sadiyapur, a village about two and a half miles from Allahabad, in the month of December 1931. It is the first representative of this genus and the family Opecœlidæ and the only trematode with ani hitherto recorded from India.

The fish host of the parasite which inhabits deep burrows and human or other mammalian skulls is procured with great difficulty. Hence many hosts could not be examined. The intestine of a single fish examined was found to be infected with about twenty distomes.

## Opegaster anguillii n. sp.

The distomes are found feebly attached to the mucous membrane of the intestine of *Anguilla bengalensis*, the common fresh water Indian eel. The worms, when placed in normal salt solution, show very slow movements, except the neck which is highly extensile. They did not survive in salt solution for more than thirty six hours. The body of the parasite is so thin and transparent that, by applying just slight pressure, the whole anatomy can be made out under a low magnification of the microscope.

The distomes, in the living condition, are almost white, with a pinkish patch in the middle. The body is thin and transparent, oval or somewhat elongated in outline. It is broader in the posterior half and tapers anteriorly to a bluntly pointed end. The body wall is smooth. The worms, on fixation, measure 2·70 to 4·42 mm. in length and 0·84 to 1·34 mm. in maximum breadth, in the region of the acetabulum. The subterminal oral sucker, measures 0·18 to 0·25 mm. in diameter. It is much smaller than the ventral sucker, which measures 0·30 to 0·42 mm. in diameter. The ratio between the two suckers, therefore, is 1 : 1·7. The ventral sucker, with thick protruding muscular walls, is situated in the anterior third of the body, at 0·64 to 0·98 mm. distance from the anterior end. The highly muscular wall of the acetabulum is both anteriorly and posteriorly thrown into two conspicuous finger-like papillae which lie close to each other. A very short but distinct prepharynx measures 0·06 in length and 0·0137 mm. in its maximum breadth. The long, slender, oesophagus (0·137 to 0·41 mm. by 0·052 mm.) is narrower anteriorly but it broadens gradually at the base of the intestinal bifurcation midway between the oral and ventral suckers. The course of the intestinal caeca, 0·07 mm. in maximum breadth, is almost straight upto the posterior margin of the posterior testis, whence they gradually converge centrad and unite in the middle line, just behind the posterior extremity of the intracaecal vitellaria. From the mid-transverse part of the united caeca there arises a short backwardly directed process which opens to the exterior through the anus, situated ventrad, a little anterior to the terminal excretory pore.

The main reproductive organs lie in the third-quarter of the body. The testes are transversely broad, but their outline is not constantly uniform in all specimens examined. Hence it is enough to say that they have almost entire margin and are situated slightly obliquely to one another or in tandem. The anterior testis is 0·21 to 0·368 mm. long and 0·34 to 0·494 mm. broad. Its front margin is 0·526 to 0·691 mm. behind the acetabulum, either at the level of the posterior margin of the ovary, or a little behind it. The posterior testis (0·27 to 0·484 by 0 347 to 0·526 mm.) lies 0·01 to 0·10 mm. behind the posterior margin of the anterior testis. In one specimen, the lateral ends of the posterior testis extend somewhat caudad so as to give it a kidney-shaped appearance. The vasa efferentia arise from the middle of the anterior margin of the testes and run almost parallel to one another in the median plane. They unite, just behind the base of the highly extensible vesicula seminalis externa to form a very short vas deferens. The vesicula seminalis externa is provided with thin membranous walls and is situated to the right side of the acetabulum. It is broad in the posterior half of its length and tapers anteriorly to form a long slender tube, which runs cephalad, obliquely to the left of the body. It varies considerably both in position and dimensions because of its highly extensile nature. In some mounted specimens it extends to the level of the anterior margin of the ventral sucker ; in others it goes far behind, as far back as 0·263 mm. distance behind the

posterior margin of the acetabulum. A very small cirrus pouch lies obliquely near the level of the intestinal fork. It has thin membranous walls and contains a short vesicula seminalis interna, a slightly curved pars prostatica, and a small narrow ductus ejaculatorious.

The ovary is submedian, transversely broad and almost trilobate to irregularly ovoid measuring 0˙042 to 0˙17 mm. in length and 0˙189 to 0˙315 mm. in its maximum breadth. It is situated to the right side of the body, 0˙42 to 0˙52 mm. behind the caudal margin of the acetabulum. The oviduct arises from about the middle of the anterior margin of the ovary, and runs cephalad. parallel to the body wall for a little distance, and then turns centrad to enter into the shell gland mass. A short transversely oblique Laurer's canal originates from the oviduct near the right margin of the shell gland mass, just at the point where the oviduct enters the latter. The genital pore lies to the left side, almost midway between the intestinal bifurcation and the body margin. The uterus has a few short transverse coils, lying between the genital pore and the transverse vitelline duct. It does not extend posterior to the ovary in this species. The coils mostly occupy the left half of the body and the number of eggs, (0˙0737 by 3˙0316 mm.) contained in the uterus, varies from 16 to 40.

The vitellaria are highly developed. They are situated laterally from about the middle of the oesophagus to the caudal extremity, and also fill up the body space behind the posterior testis. The vitelline follicles, at some places overlap the intestinal cæca or even extend further inward ; they measure on an average, 0˙10 to 0˙13 mm. in length and 0˙062 mm. in breadth. There are present, on each side, anterior and posterior vitelline collecting ducts which unite with one another either at the level of the ovary, or a little anterior to it to form the transverse right and left vitelline ducts. The transverse ducts join, in the middle, to form a large elongated, vitelline reservoir which opens into the ootype by a very short narrow conical duct. It is interesting to note that in this species, the posterior vitelline ducts run inside and almost parallel to the intestinal cæca behind the middle of the posterior testis, and continue into one another in an arc in front of the continuation of the intestinal cæca which lies close behind. The duct of each side receives one internal and two external branches from the intracaecal and lateral vitelline follicles, respectively, which lie behind the middle of the posterior testis.

The excretory system is typical of the genus and was studied mainly in living specimens. It consists of a simple median tubular excretory vesicle extending from the posterior margin of the ovary to the caudal extremity. Its anterior-most vesicular part between the ovary and the cephalad margin of the anterior testis is slightly swollen. This swollen part receives, latero-posteriorly, on each side a short transverse excretory canal, which is formed, near the intestinal caeca, by the union of the main ascending and descending excretory collecting tubules. The ascending

collecting tubules run almost straight and parallel to the body wall and are formed each by the union of three narrow short branches at the level of the pharynx. On its way backwards each ascending tubule is joined by internal and external branches which run from behind forwards. As the posterior half of the body is occupied by massive reproductive organs, and highly developed vitellaria, course of the descending excretory canals could not be made out. The excretory vesicle opens to the exterior by the terminal excretory pore, which is provided with highly muscular walls.

TABLE COMPARING CHIEF CHARACTERS OF THE FOUR SPECIES OF THE GENUS
OPEGASTER OZAKI, 1928.

|  | O.ovatus. | O.rectus. | O.brevifistula. | O.anguillii n. sp. |
|---|---|---|---|---|
|  | mm. | mm. | mm. | mm. |
| 1. Length of body ... | 1·80-2 00 | 2·15-2·4 | 1·90-2·90 | 2·64-4·20 |
| 2. Breadth of body ... | 0·64-0·75 | 0 65-0·72 | 0·70-1·00 | 0·89-1·38 |
| 3. Diameter of oral sucker ... | 0·14-0-16 | 0·15 | 0·18-0·21 | 0·189-0·263 |
| 4. Diameter of ventral sucker ... | 0·20-0·21 | 0·23 | 0·26-0·30 | 0·31-0·44 |
| 5. Papillae on ventral sucker ... | ABSENT | ABSENT | (Six in number finger like). | (Four in number finger like.) |
| 6. Pharynx diameter... | 0·085 | 0·086 | 0·12-0·14 | 0·063-0·137 |
| 7. Oesophagus ... | 0·11-0·17 long. | 0·18 long. | ABSENT | 0·137-0·41 long, |
| 8. Ratio of oral to ventral sucker ... | 1 : 1·37 | 1 : 1·53 | 1 : 1·2 | 1 : 1·7 |
| 9. Position of reproductive organs. | In last third of body. | In last third of body. | In middle third of body. | In third quarter of body. |
| 10. Testes ... | Irregularly lobed, caudad slightly oblique. | Irregularly lobed, caudad tandem. | Globular to ovoid, with somewhat irregular outline ; slightly displaced to left. | Globular to avoid, with almost regular outline ; tandem or slightly oblique. |
| 11. Extension of vesicula seminalis externa. | To level of middle of acetabulum. | To level of acetabulum. | To posterior border of acetabulum. | Variable, from anterior margin of acetabulum to far behind acetabulum |
| 12. Shape and position of ovary. | Trilobate, slightly separated from ant. testis, submedian. | Trilobed, transversely elongated ; median. | Trilobate or irregular ; submedian. | Transversely broad ; submedian. |
| 13. Anterior extent of vitellaria. | To level of intestinal fork. | To level of intestinal bifurcation. | To level of pharynx. | A little cephalad to intestinal fork. |

TABLE COMPARING CHIEF CHARACTERS OF THE FOUR SPECIES OF THE GENUS
OPEGASTER OZAKI, 1928—*(Contd)*.

|  | O.ovatus. | O.rectus. | O.brevifistula | O anguillii n. sp. |
|---|---|---|---|---|
| 14. Uterus ... | Transversely much coiled. | Transversely much coiled | Transversely much coiled, coils between ant. testis and acetabulum somewhat over-lap. int. caeca. | Few transverse coils between acetabulum and transverse vitelline duct ; mostly in left half of body. |
| 15. Eggs ... | Many 0·045-0·052 by 0·030-0·036 mm. | Many 0·045-0·050 by 0·030-0·035 mm. | Many 0·054-0·060 by 0·033-0·037 mm. | Few (16 to 40) 0·07 by 0·0316 mm. |
| 16. Ratio of length to breadth of body. | 2·73 : 1 | 3·32 : 1 | 3·01 : 1 | 3·22 : 1 |
| 17. Host ... | Parapercis ommatura. Jordan and Synder Japan. | Parapercis ommatura. Jordan and Synder Japan. | Amia lineata Japan. | Anguilla bengalensis. Gray and Hardw. India. |

It would be clear from the above table that the two species *Opegaster ovatus* and *O.rectus*, which are found in the same host, resemble very closely in the general topography, of both digestive and reproductive organs, with certain miner differences in the measurements of digestive and reproductive organs. After a careful study of more than ten specimens of the new species described in this paper, it is quite clear to me that the position and measurements of both digestive and reproductive organs are liable to variations due to contraction and extension of the living specimens and by pressure in others in making entire mounts. Hence, if species are to be created on miner differences based only in slight variations in the shape and position of the testes and ovary, in the ratio of oral to ventral sucker, in the extent of vesicula seminalis externa, and lastly in the ratio of the length to breadth of the body, a number of species can be created out of the same form collected from the same host and location.

In my opinion the characters on the basis of which Ozaki has created species *O. ovatus* and *O.rectus*, namely the positions of testes and ovary, the ratio of oral to ventrel sucker, the extent of veslcula seminalis externa, and lastly the ratio of the length to breadth of the body, are not constant in members of the same species as is clearly established by the study of *Opegaster anguillii* n. sp. described in this paper. Therefore I suggest that the two species *O. rectus* and *O. ovatus* be merged together under the name *C. ovatus*, which Ozaki recognised as the type species of his genus.

Of the species of the genus thus known, *Opegaster anguillii* n. sp. is the largest and comes somewhat intermediate between *O. ovatus* and *O.brevifistula*

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Ozaki. *Opegaster* anguillii resembles the Japanese species *O. brevifistula* Ozaki in the shape of the body, in shape of the reproductive organs, in disposition of the vitelline glands and possession of papillae on the ventral sucker. But it differs from it in the large size of its body, in the presence of an oesophagus, in the number of finger-like papillae on the ventral sucker (four in *O. anguillii* ; six in *O. brevifistula*), in the ratio of oral to ventral sucker, in the position of the reproductive organs, in the lesser number of uterine coils and the contained eggs, and lastly in the absence of stump-like projection of the eggs.

It also resembles the other Japanese species *O. ovatus* Ozaki in the shape of the body, in the presence of oesophagus and dispopition of vitelline glands. But it differs from it in the large size of its body, in the presence of papillae on the ventral sucker, in the position and shape of the testes and ovary, in the ratio of the oral to the ventral sucker, in the lesser number of uterine coils and the contained eggs, and lastly in the absence of a stump-like projection in the egg. And hence it is a new species which 1 name *opegaster anguillii* with the following specific characters.

Length 2·64 to 4·20 mm., maximum width 0·89 to 1·38 mm. ; ratio of oral to ventral sucker 1 : 1·7 ; ventral sucker with two anterior and two posterior papillae ; redroductive organs in the third quarter of the body ; testes globular to ovoid with almost regular outline, in tandem or slightly oblique ; ovary transversely broad, submedian ; vitellaria extend a little cephalad to the intestinal fork ; uterus with few transverse coils between the acetabulum and the transverse vitelline duct ; number of eggs in the uterus 16 to 40 ; size of eggs 0·07 by 0·0316 mm.

Host.   Anguilla bengalensis Gray and Hardw.

Location.   Intestine.

Locality.   Allahabad, U. P. India.

### EXPLANATION OF LETTERING.

| a. | ... | Anus. | O. S. | ... | Oral Sucker |
| a. T. | ... | Anterior testis | Ov. | ... | Ovary |
| C. S. | ... | Cirrus Sac. | Ph. | ... | Pharynx |
| ex. P. | ... | Excretory pore | T. | ... | Posterior testis |
| G. P. | ... | Genital pore | V. S. | ... | Ventral Sucker |
| i. c. | ... | Intestinal Caeca | Ves. sem. ex. | | Vesicula semi- |
| Oes. | ... | Oesophagus | | | nalis externa. |

### EXPLANATION OF FIGURES

Figs. 1.      Ventral view of *Opegaster anguillii* sp. n. showing the anatomy.

Figs. 2 to 5.   Semi diagramatic sketches showing the variety of shapes and positions of the testes in different specimens.

*Reference*

Ozaki. Y.   On some trematodes with Anum.   Japanese Journal of Zoolony. Vol II No. 1, 1928

FIG. 1.

1 mm.
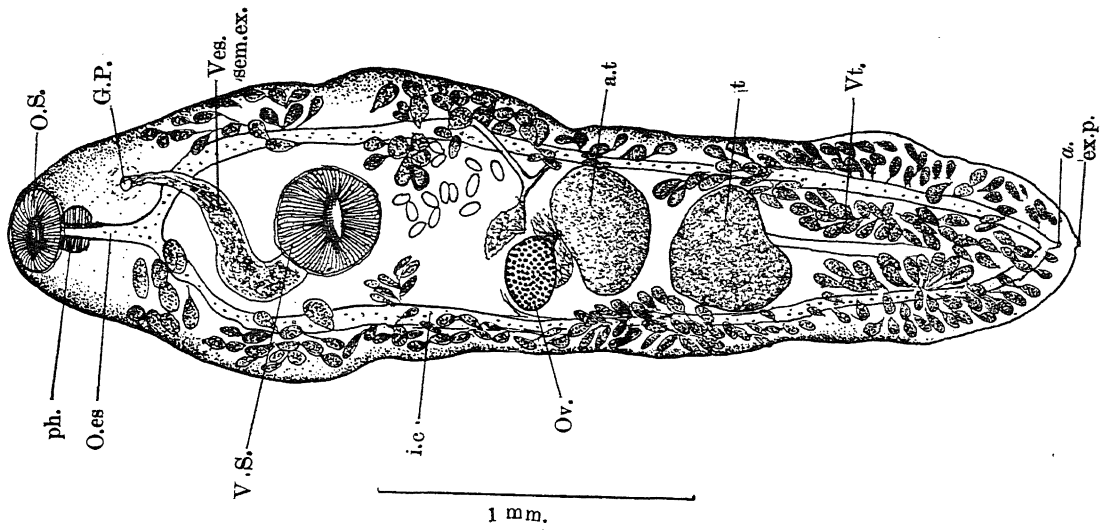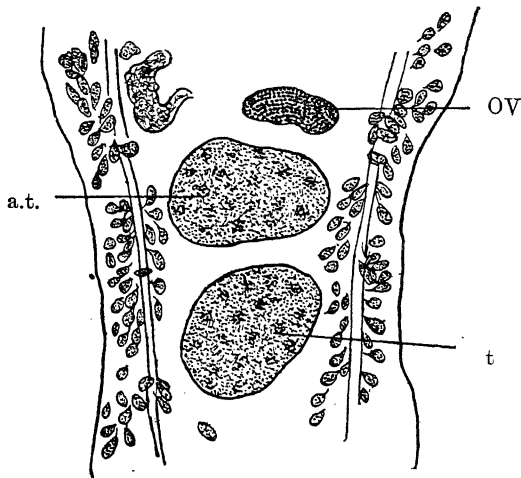


FIG. 2.
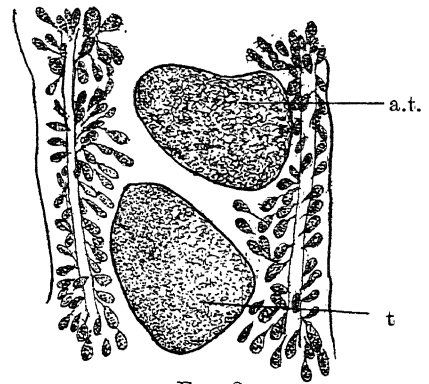


FIG. 3.
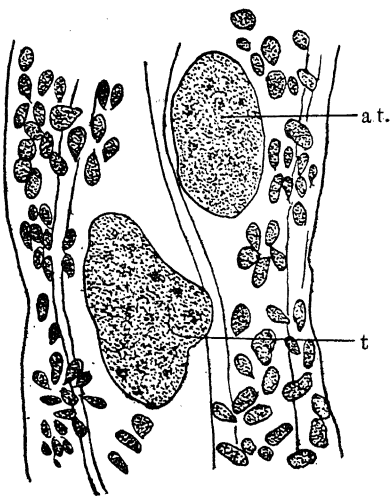


Fig. 4.
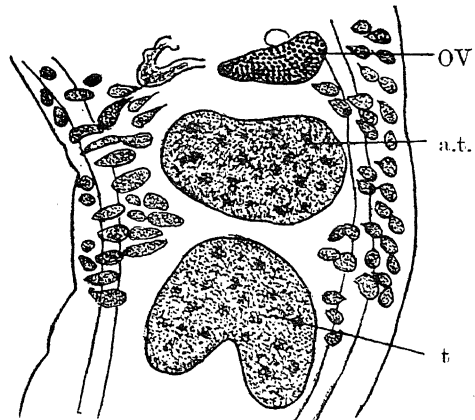


FIG. 5.

# A CONTRIBUTION TO THE MORPHOLOGY OF
## *DIGERA ARVENSIS**

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Communicated by Dr. J. H. Mitter

## INTRODUCTION

Very little information concerning the morphology of the family Amarantaceæ is to be found in literature. Fischer (1880) found that in *Gomphrena decumbens* the megaspore mother-cell gives rise to three megaspores only. Guignard (1882) observed the development of the embroyo sac of *Celosia argentia* and found that the endosperm originates by free cell formation. Dahlgren (1916) also figures three megaspores of which the lowest develops into the embroyo sac in *Amarantus blitum* L. It was therefore suggested by the late Dr. Dudgeon that a study of the morphology of any member of the family might prove interesting.

### Material and Methods

Flower buds of *Digera arvensis* in all stages of maturity were collected at various times of the day and fixed on the spot in various fixing agents. Of these stock-Chromo-Acetic acid gave by far the most satisfactory results. An air pump was used to hasten the penetration. The material was washed in running water for 24 hours, dehydrated in Alcohol, cleared in Xylol and embedded in 56°C. to 58°C. paraffin. Both transverse and longitudinal sections were cut at 5 to 10 microns and were fixed on the slide with modified Land's fixative replacing gum-arabic with gloy.

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Sections were stained in a combination of Safranin and Gentian violet or Heiden-hain's Iron-Alum-Haematoxylin. Pieces of stems of different ages were fixed in Formalin-acetic-alcohol, dehydrated, embedded and cut at 6 to 10 microns. Slides were mainly stained in Safranin and Light green. Free hand sections of the stem were also cut and examined.

## Investigation

*Digera arvensis*, a member of the family Amarantaceæ is a slender annual weed of cultivation, some-times becoming perennial, with spreading prostrate branches. "It is widely distributed throughout the plains of N. India from the Punjab to Bengal and in W. C. and S. India extending to Ceylon, Afganistan, Balochistan, Arabia and North Africa" (Duthie). It flowers usually after the rains are over. The flowers are protandrous and are arranged in lax axillary peduncled spikes 1 to 5 inches long. The flowers are very small. There is a single whorl of perianth which is five lobed. The stamens are five in number. The ovary is one celled with a single anatropous basal ovule.

**Stem Anatomy.** The structure of the stem shows the usual anomalous growth found in the Centrospermales. A transverse section of a young inter-node shows a single layered epidermis on the outside. There are no hairs. Beneath the epidermis is the thin cortex with a few layers of collenchyma at the ridges. The endodermis is not distinct. The pericycle is narrow. The bundles are in three rings. The outermost ring consists of many small bundles. The innermost ring comprises only of two large bundles. The bundles of the middle ring are rather loose and contain 6 to 10 strands. (Fig. 1).

Intrafascicular cambium is present in the bundles of all the three rings. In the two inner rings this cambium by its meristematic activity develops only a little of the xylem and phloem elements. But in the outermost ring interfascicular cambium also develops which unites with the bands of intrafascicular cambium and forms a complete ring. This cambium ring by its activity gives rise to a large amount of xylem and phloem in the intrafascicular region and conjunctive tissue in the interfascicular region. (Fig. 2).

After a time the activity of this cambium stops short and another supernumerary cambium develops in the region of pericycle and gives rise to another ring of bundles. In this way successive meristematic rings arise each producing a ring of vascular bundles.
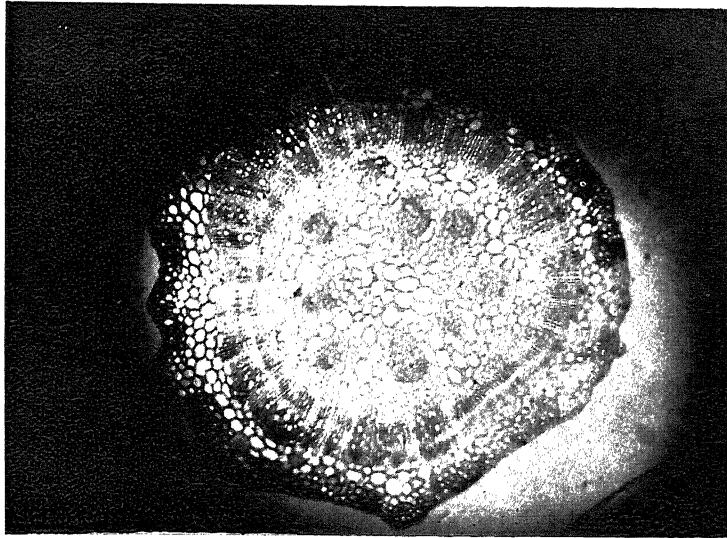
Fig. 1.—A microphotograph of a transverse section of a young
internode of *Digera arvensis* showing the rings of bundles.
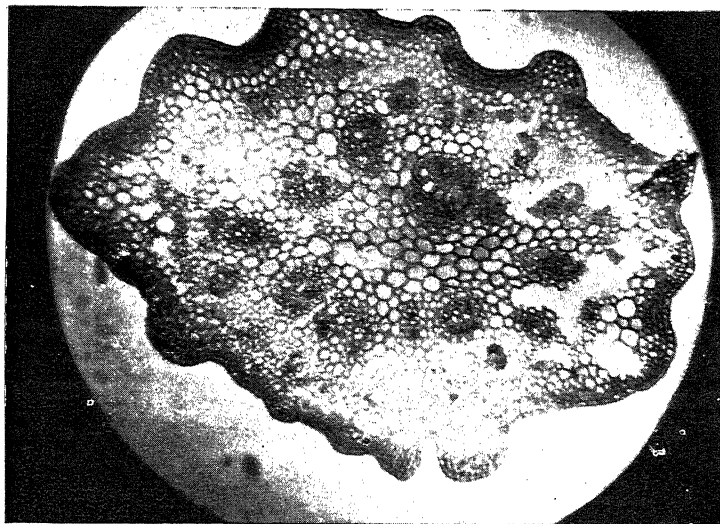


Fig. 2.  A micro photograph of an older stem.  The intra-
fascicular cambiums of the outer ring of bundles have
joined to produce a complete cambium cylinder.
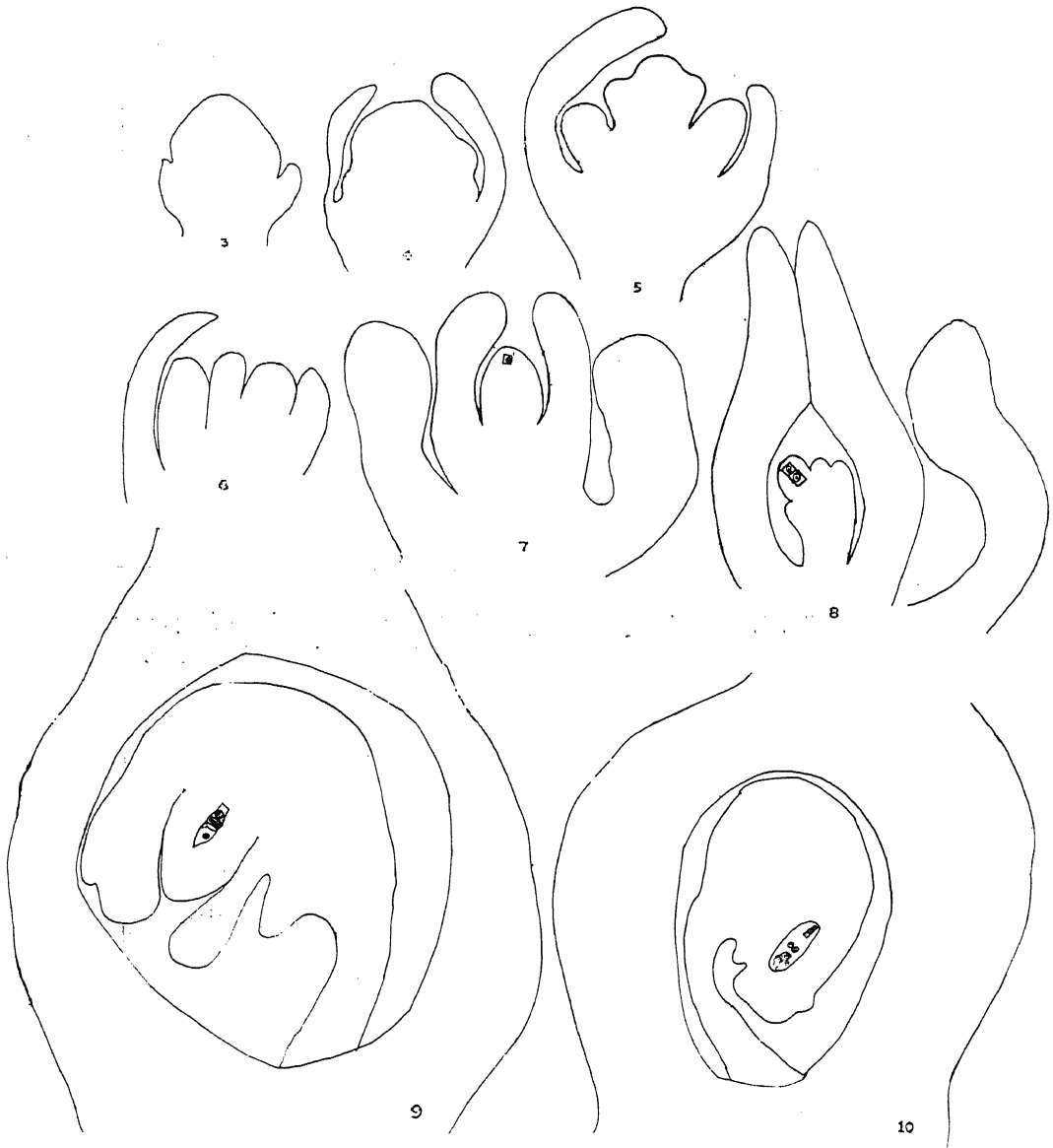
Figs. 3 to 10—Organogeny and development of the ovule ; fig. 3 appearance of perianth ; figs. 4, 5 appearance of stamens ; fig. 6 development of the carpel ; fig. 7, the appearance of the hypodermal archesporial cell ; fig. 8, carpel closing over the nucellus, archesporial cell divided into primary wall cell and megaspore mother cell, a stamen and appearance of the two integuments : fig. 9, curved ovule with three linear megaspores, (figs. 3 to 9 × 160) ovule with eight nucleate embryosac fig. 10 × 80.

**Organogeny.**—The flowers arise as lateral conical outgrowths from the apex of the central axis. From this conical protuberance the different parts of the flower arise in acropetal succession. The first to develop is the single whorl of perianth (fig. 3). No indication of the other whorl has been found. The perianth is followed by the stamens (figs. 4. 5), The tip of the axis becomes the terminal nucellus which protrudes forward to form the single ovule. The nucellus from both sides of the base of the ovule pushes forward to enclose the ovule completely forming the wall of the ovary (figs. 6, 7. 8).

**Microsporogenesis.**—As usual there are four microsporangia, which are derived from the outer layer of the periblem. At first there is a homogenous mass of meris-tematic cells covered by the epidermis. This becomes four lobed at an early stage. Almost simultaneously with the appearance of the lobes the sporogenous tissue developing from the outer layer of the periblem becomes evident (fig. 11) This tissue is distinguished from the adjacent cells by its large size, bigger nucleus and somewhat different reaction to stains.

The archesporial cell divides by a periclinal wall forming a primary parietal cell which forms the wall of the anther and a primary sporogenous cell (fig. 12). The primary parietal cell after further divisions gives rise to the endothecium, one middle layer and the tapetum. The formation of the tapetal jacket coincides with the mother-cell stage of the microspore and reaches its maximum during the formation of the tetrads. During this period they greatly increase in size and become a layer of two nucleate cells (fig. 14).

During the period of the development of the parietal cell, the primary sporo-genous cell increases considerably in size and then divides forming the spore mother cells. They grow larger and round up somewhat. Then follows the heterotypic reduction division. The nucleus of the microspore mother-cell shows a net-work upon which are distributed the chromatin granules and one distinct globular nucleol-us. The cytoplasm of the spore-mother-cell does not appear to be as dense as that of the tapetal cells which are easily distinguishable by their heavier stain. Fig. 15 shows the nuclear net-work quite pronounced. Fig. 16 represents a stage of synizesis where the chromatin thread have contracted into a knot, the nucleolus although centrally located is distinguishable. At diakinesis stage (fig. 17) the chromosome rods lie scattered throughout the nucleus.

As the chromatin thread breaks up into rod like chromosomes the nuclear membrane disappears. The spindle appears as a number of fibers which attach them-selves to the chromosomes and converge at the poles. The microspore mother cells now round off and float inside the pollen chamber, the binucleate tapetum surround-

ing them. Because of the developing tapetum the middle layer cells loose their protoplasm and become flattened and finally disorganise.

In fig. 18 the prominent rod like chromosomes are approaching the poles. In the telophase stage (fig. 19) the chromosomes have reorganised themselves. After the first reduction division the two nuclei immediately enter the homotypic division without the formation of any cell wall. Usually only one stage is represented in one anther during the heterotypic division. But in some cases it was observed that while one anther lobe was at diakinesis stage the other one was at the late anaphase stage and the lobe of another anther of the same flower had formed the tetrads. But such cases were few. In the homotypic division also similar variations were observed. While in one stamen the microspore mother cell was in the midst of the second reduction division, tetrads had already been formed in the other stamen. The arrangement of the microspores in the tetrads may be either bilateral or tetrahedral, the latter is more common (fig. 21). The formation of the cell walls is simultaneous. The four grand daughter nuclei are alike in size, amount of chromatin and in having only one nucleolus. (Fig. 22).

After the two divisions the young microspores become invested by a wall which is independent of the wall of the mother-cell. The spores then free themselves from each other and round up (fig. 23). The wall soon becomes differentiated into two layers. The inner intine consists of cellulose and the outer cutinised exine becomes somewhat sculptured. The number of germ pores are from five to eight.

The nucleus of the microspore now divides up into two nuclei, one of them becomes bigger than the other and is the tube nucleus, the other smaller is the generative nucleus (fig. 24). A generativee cll more or less becomes organised about the generative nucleus and is in the begining spherical but later becomes lenticular (fig. 25).

The generative cell divides in the pollen chamber long before dehiscence. It is of interest to add that in a longitudinal section of an anther the various stages in the meiotic divisions have been observed in their natural sequence by passing from the end of the anther towards the middle or from one end to the other. In fig. 26. the chromosomes have arranged themselves at the equatorial plate of the chromatic figure. In telophase the chromosomes have organised themselves into two daughter nuclei (fig. 27). The two nuclei thus formed become associated with the cytoplasm in such a way that more or less definite male cells are organised. But only the nuclei are most conspicous and form the bulk of the male cells. The male cells when first formed are spherical (fig. 28) but soon become lenticular (fig. 29).

**Megasporogenesis :**—There is a single cauline ovule and the apex of the axis becomes the nucellus.

At the time when the microspore mother cells are in the early heterotypic prophase, the ovule appears as an erect rounded protuberance developing from the placental tissue. This protuberance soon becomes somewhat pointed and due to more rapid growth on one side of this mass than on the other, the ovule gradually becomes anatropous (figs. 7 to 10).

The megasporangium originates as does the microsporangium from the outer layer of the periblem. At first the epidermis of the member upon which the ovule is to appear is even. Radial cell divisions in the epidermis and in all directions in the hypodermis result in a mass of tissue which protrudes forward and forms the nucellus of the forming ovule. One of the hypodermal cell soon becomes slightly enlarged and takes a deeper stain and is differentiated as the primary archesporial cell (fig. 30). About this time a slight protruberance at the base of the nucellus indicates the first integument. The appearnace of the second integument begins soon after. The primary archesporial cell divides by a periclinal wall to form the primary wall cell on the outside and the primary sporogenous cell on the inside (fig. 31). The primary wall cell divides anticlinally and pericinally forming many layers of cells between the epidermis and the megaspore mother cell (fig. 32). The primary sporogenous cell enlarges considerably and without any further divisions functions as the megaspore mother cell. It then undergoes division. At the time of the heterotypic division the mother cell is about twice as long as broad. Its nucleus is near the micropylar end of the cell and contains one conspicuous nucleolus imbedded in the chromatin net-work. The chromatin net work condenses finally into a dense synizetic knot (fig. 32). On recovering from synizesis the open spireme stage is reached (fig. 33). Fig. 34 represents the metaphase stage where chromosomes have arranged themselves at the equatorial plate. Fig. 35 shows the late telophase stage.

After the heterotypic reduction division the megaspore mother cell is divided by a cell plate (fig. 36). As a result of the second homotypic division a linear row of three megaspores is produced (fig. 37). Two of the megaspores towards the micropylar end degenerate and the one at the chalazal end functions as the embryosac mother cell (fig. 38). The embryosac mother cell now increases in size considerably. The vacuoles on either side of the nucleus become prominent (fig. 38.) The nucleus of the functional megaspore divides into the primary antipodal and the primary micropylar nuclei. This division takes place near the micropylar end of the megaspore and one daughter nucleus moves towards the chalazal end of the embryosac (figs. 39, 40). Both nuclei then divide forming two nuclei at each end

of the sac. The two micropylar nuclei lie transversely and the two chalazal ones lie in the plain of the long axis of the embryosac (fig. 41). All through the four nucleate stage the embryosac continue to elongate and the central vacuole considerably increases in size. After the third division the typical eight nucleate embryosac is formed (fig. 42). One nucleus from each pole migrates towards the center leaving three nuclei at each end. Walls are now laid down around the nuclei remaining at each end (fig. 43). The egg-apparatus consists of three more or less pear shaped cells, the two synergids and the egg. In young stage the nucleus in the synergids is in the basal portion of each and the vacuole lies above it towards the micropylar end (fig. 43). But in the mature stage a large vacuole appears near the base of the cell and the micropylar one disappears. The nucleus also changes its position and is found in the dense protoplasm above the basal portion (fig. 44). The egg extends into the embryosac beyond the synergids. When mature it is pearshaped, has a large vacuole in its apical region and the nucleus is situated near the basal portion surrounded by the dense cytoplasm (fig. 44).

The antipodal cells are more or less triangular in section (fig. 44) and show a tendency to degenerate early.

The polar nuclei come to lie close together near the egg and fuse before fertilization forming the primary endosperm nucleus which contains only a single large nucleolus.

**Fertilization.**—At the time of fertilization the embryosac becomes considerably elongated and curved. The synergids and the antipodals degenerate. In several cases the pollen tube has been observed to lie near the egg (figs. 45, 46). No actual fertilization has been observed but in several cases it was found that the nucleus of the egg contained two nucleoli, one smaller and the other bigger. Probably the smaller one represents the male nucleolus and the bigger one represents the female. Two dissimilar nucleoli have also been found in the endosperm nucleus in the same embryosac suggesting double fertilization (fig. 45).

**Endosperm.** The endosperm nucleus is the first to divide. The division is free nuclear. (Figs 47, 48).

**Embryo.** Young stages of the embryo were not obtained. Fig. 47 shows the quadrant stage of the embryo with two small suspensor cells. The development of the embryo corresponds with the Capsella-type. Fig. 48 shows a little older stage of the embryo.

In conclusion I wish to express my sincere thanks to the late lamented Dr. Winfield Dudgeon for his helpful suggestions during the progress of this investigation.

## Summary

1. *Digera arvensis*, a member of the family Amarantaceæ, is a common weed of cultivation and flowers usually after the rains are over.

2. The structure of an young stem shows in transverse section three rings of bundles. The inner bundles have only intrafascicular cambiums and there is very little secondary growth. In the outer ring a complete ring of the cambium is formed and a broad zone of an anomalous wood is produced.

3. The floral parts develop in acropetal succession there is only one whorl of perianth. The ovule is cauline. The single carpel arises from the apex of the nucellus.

4. Microsporogensis follows the usual course of development. The middle layer is one layered. The tapetum when mature is binucleate. Microspore mother cells are many in each lobe. The microspores are arranged either tetrahedrally or isobilaterally. The generative cell divides in the pollensac, long before dehiscence, into two male cells. At the time of shedding, the microspore is three nucleate.

5. A single hypodermal archesporial cell of the nucellus divides to form the primary wall cell and the megaspore mother cell.

6. There are two integuments.

7. In consequence of two divisions the megaspore mother cell forms a linear row of three megaspores only. The chalazal one functions as the embryosac mother cell and the other two degenerate.

8. A typical eight nucleate embryosac is formed. The polar nuclei fuse before fertilization. At the time of fertilization the synergids and the antipodals degenerate.

9. Actual fertilization could not be followed but two unequal nucleoli have been observed inside the egg and the endosperm nuclei.

10. The formation of the endosperm is by free nuclear division.

11. The development of embryo is Capsella type.

17

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## Explanation of Plates

All figures have been reduced to one half in reproduction—

Fig. 11. Transverse section of a portion of a young anther showing two archesporial cells. X 1600.

Fig. 12. Archesporial cell divided into primary wall cell and primary sporogenous cell. X 1600.

Fig. 13. The wall cell has divided anticlinally. X 1600.

Fig. 14. Transverse section of a portion of anther showing endothecium, one middle layer, tapetum and microspore mothercell. X 1600.

Fig. 15. Nucleus of the microspore mothercell showing prominent nuclear net work. X 1600.

Fig. 16. Microspore mothercell in synizesis. X 1600.

Fig. 17. Same at diakinesis. X 1600.

Fig. 18. Same, showing the anaphase of the first reduction division. X 1600.

Fig. 19. Microspore mothercell in late telophase stage. X 1600.

Fig. 20. Two microspore mothercells in telophase of the second reduction division. X 1600.

Fig. 21. Microspores in tetrads. X 1600.

Fig. 22. The microspores separated from the mothercell wall. X 1600.

Fig. 23. One nucleate pollen grain. X 1600.

Fig. 24. Two nucleate pollen grain, generative nucleus is spherical. X 1600.

Fig. 25. The same, generative nucleus has become lenticular. X 1600.

Fig. 26. Generative nucleus in metaphase stage. X 1600.

Fig. 27. Same in telophase stage. X 1600.

Fig. 28. The generative cell divided into two spherical male cells. X 1600.

Fig. 29. Three nucleate pollen grain at the time of shedding. The male cells have become lenticular. X 1600.

Fig. 30. Longitudinal section of young nucellus showing the hypodermal archesporial cell, X 1600.

Fig. 31. Archesporial cell divided into primary wall cell and megaspore mothercell. X 1600.

Fig. 32. The megaspore mothercell in synizesis. X 1600.

Fig. 33. Same, open spireme stage. X 1600.

Fig. 34. Megaspore mothercell in metaphase of the first reduction division. X 1600.

Fig. 35. Same, in telophase stage. X 1600.

Fig. 36. Same, divided into two cells, a wall is laid down. X 1600.

Fig. 37. Same, divided into three linear megaspores. The middle has degenerated and the upper is degenerating the lowest is the functioning megaspore. X 1600.

Fig. 38. Functioning megaspore and the upper two degenerated megaspores. X 1600.

Fig. 39. Two nucleate embryosac with a vacuole at base. X 1600.

Fig. 40.    Same, the two nuclei migrated to the two poles with a big vacuole
            in the centre.   X 1600.

Fig. 41.    Four nucleate embryosac.   X 1600.

Fig. 42.    Eight nucleate embryosac.   X 1600.

Fig. 43.    Advanced stage of the embryosac, the two polar nuclei lying close
            together, the nucleus in the synergids is at the base and the
            vacuole towards the micropylar end.   X 1600.

Fig. 44.    Mature embryosac, the polar nuclei have fused, the vacuole and the
            nucleus in the synergids have changed their positions.   X 1600.

Fig. 45.    Same, egg and endosperm nuclei with two nucleoli and a pollen
            tube.   X 1600.

Fig. 46.    Same, the two nucleoli in the egg and endosperm nuclei fused.   X 1600.

Fig. 47.    Embryo at the quadrant stage and free nuclear division of the
            endosperm nucleus.   X 1600.

Fig. 48.    Same, more advanced.   X 1600.
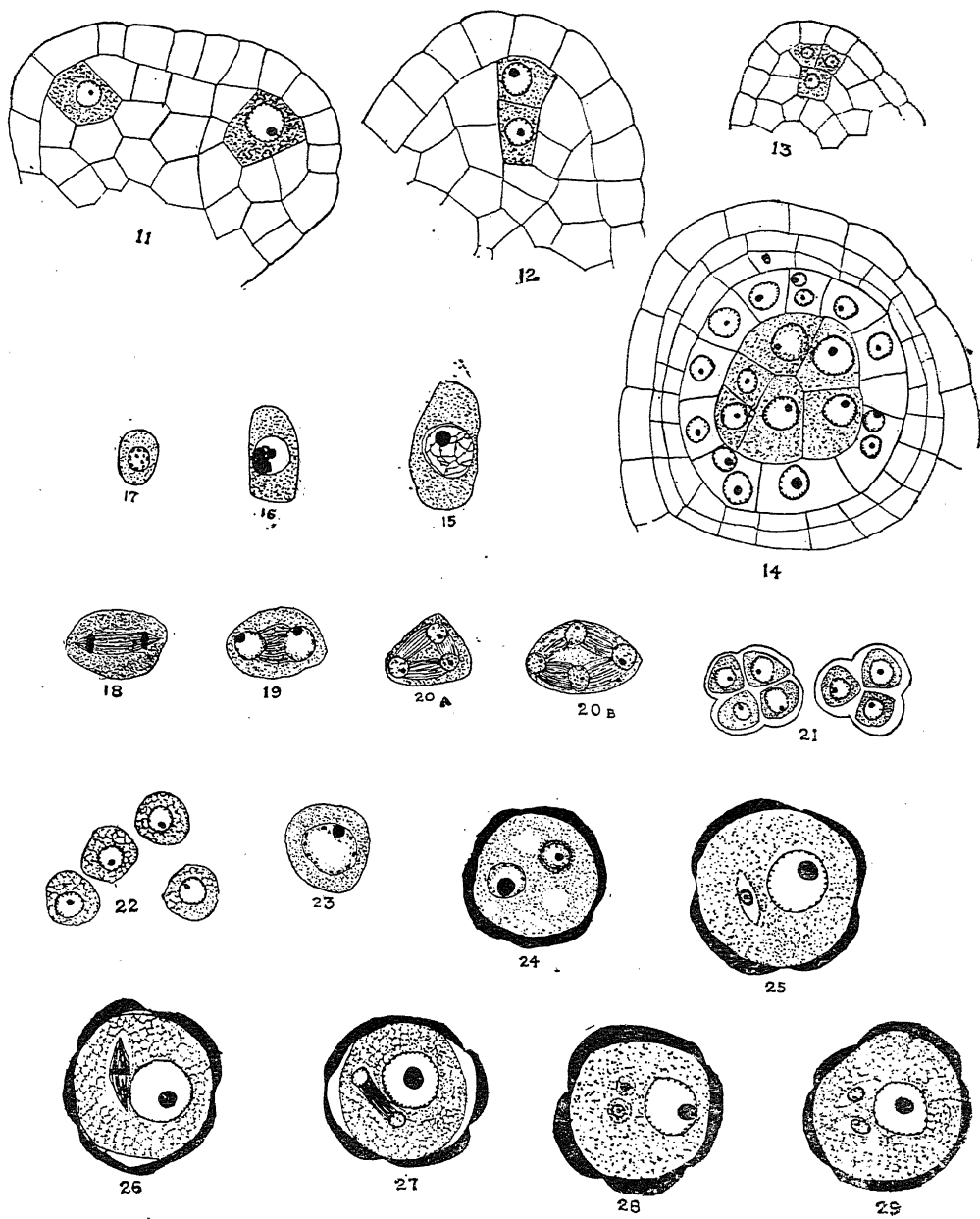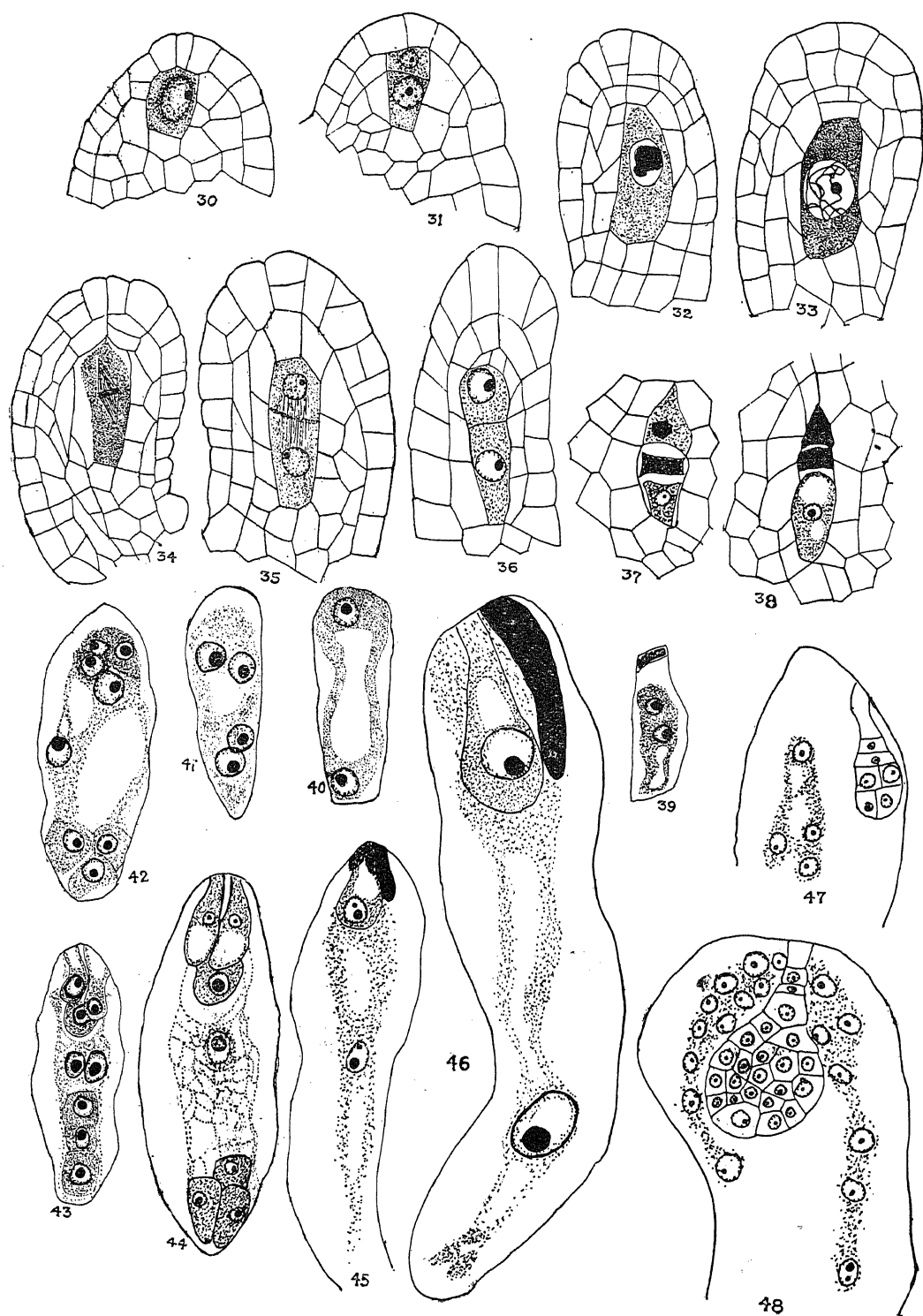
## Supplement to

**B. Sahni:** Materials for a Monograph of the Indian
Petrified Palms. Proceedings of the U. P. Academy of
Sciences, vol. I pp. 140-144.

*(The illustrations of the new species referred to in the
above preliminary paper are being issued now, as the full
paper is likely to be considerably delayed in publication.*
November 1933).

PLATE I

SAHNI: INDIAN PETRIFIED PALMS
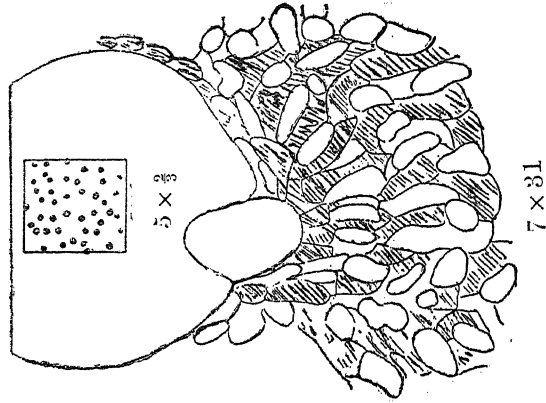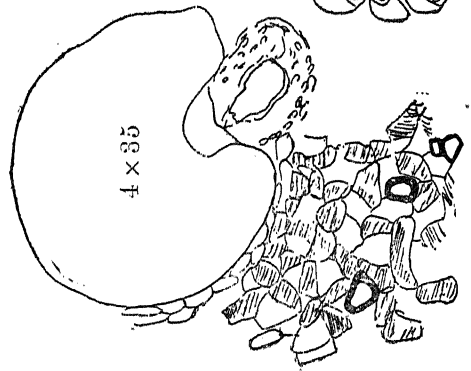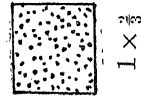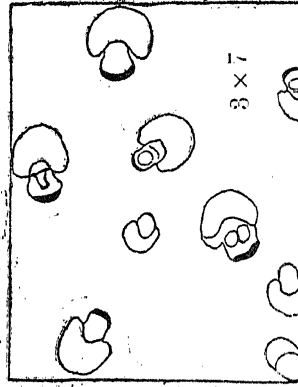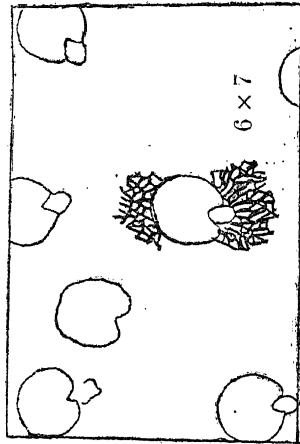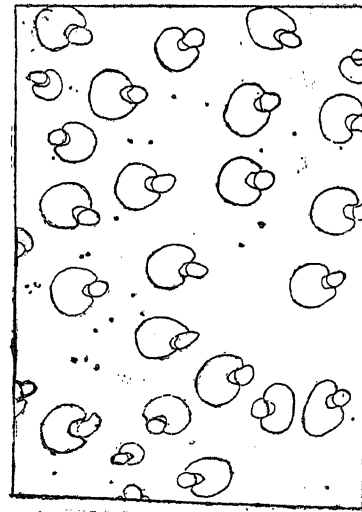
# PLATE I.

Fig. 1. *Palmoxylon Wadiai* Sahni. Diagram of part of subdermal zone, to indicate distribution and approximate size of fibrovascular bundles. ×⅔.

Fig. 2. *P. Wadiai* Sahni. Subdermal zone. The scattered dots indicate thick-walled cells in the ground-tissue. ×7.

Fig. 3. *P. Wadiai* Sahni. Central region. Posterior sclerenchymatous arch shown black. ×7.

Fig. 4. *P. Wadiai* Sahni. Bundle from subdermal zone; thick-walled cells in lacunar ground tissue. ×ca. 35.

Fig. 5. *P. jammuense* Sahni. Subdermal zone (diagrammatic). ×⅔.

Fig. 6. *P. jammuense* Sahni. Subdermal zone, very lacunar ground-tissue shown in part. ×7.

Fig. 7. *P. jammuense* Sahni. Bundle from subdermal zone, and a part of the ground-tissue. ×31.

Fig. 8. *P. sundaram* Sahni. Dermal zone (no fibrous bundles). Prof. Kalapesi's specimen. ×7.

Fig. 9. *P. sundaram* Sahni. Subdermal zone (fibrous bundles present). Kalapesi. ×7.

Fig. 10. *P. sundaram* Sahni. Central region; fibrous bundles and also very small fibrovascular bundles. (Prof. Blatter's specimen.) ×7.

# PLATE II.

Fig. 11.   *Palmoxylon indicum* Sahni. Subdermal zone (very near the periphery). Diagram to show size and distribution of bundles (cf. fig 12). × ⅔.

Fig. 12.   *P. indicum* Sahni. Inner region (not quite central). Diagram (cf. fig. 11).   × ⅔.

Fig. 13.   *P. indicum* Sahni. Subdermal zone (very near the periphery.   × 7.

Fig. 14.   *P. indicum* Sahni. Inner region (not quite central). × 7.

Fig. 15.   *P. pondicherriense* Sahni. Dermal zone.   Diagram to show size and distribution of bundles (cf. fig. 16).   × ⅔.

Fig. 16.   *P. pondicherriense* Sahni. Central region. Diagram (cf. fig. 15).   × ⅔.

Fig. 17.   *P. pondicherriense* Sahni.   Dermal zone.   × 7.

Fig. 18.   *P. pondicherriense* Sahni.   Central region.   × 7.

Fig. 19.   *P. pondicherriense* Sahni.   Border of a fibrous bundle from the ground-tissue to show stegmata.   × 85.

Fig. 20.   *P. Edwardsi* Sahni.   Subdermal zone.   Diagram. × ⅔.

Fig. 21.   *P. Edwardsi* Sahni.   The same.   × 7.

Fig. 22.   *P. caudatum* Sahni.   Subdermal zone.   Diagram. × ⅔.

Fig. 23.   *P. caudatum* Sahni.   Two fibrovascular bundles from the subdermal zone.   Vascular part usually much crushed and projecting far out like a tail.   × 18.

Fig. 24.   *P. Mathuri* Sahni. Central region (?) ; diagram, to show distribution and approximate size of fibrovascular bundles.   × ⅔.

Fig. 25.   *P. Mathuri* Sahni. Central region (?) ; fibrovascular bundles very small, far between, and quite irregularly orientated in a very lacunar ground-tissue with numerous very slender fibrous bundles,   × 18

PLATE II
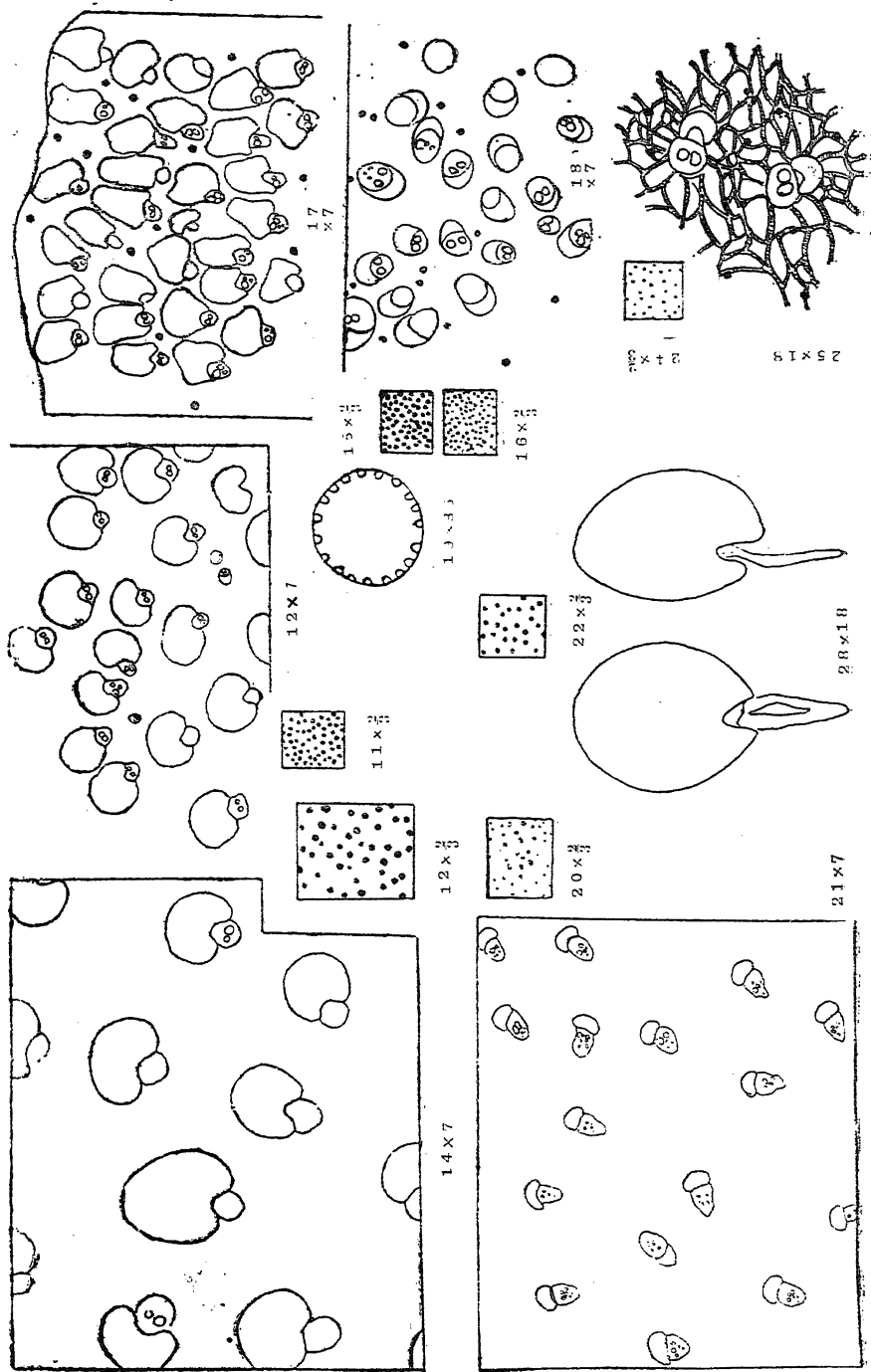
## THE PROBLEMS OF STELLAR STRUCTURE

### Part I

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Communicated by Prof. M. N. Saha

The first application of New Quantum Statistics to Astrophysics was contained in a very suggestive paper by Fowler.[1] This has been followed by the work of Frenkel,[2] Stoner,[3] and others. Recently Milne [4] has incorporated the Fermi-Dirac statistics in his new attack on the fundamental problem of Stellar Structure which was initiated by Eddington in his well-known researches about a decade ago. These new results discovered by Milne are of great significance and wide application.

The purpose of this paper is to give a critical but brief discussion of the present position regarding the fundamental problem of the stellar structure. Incidentally it also provides a necessary background for a previous paper in the Monthly Notices[5] and for subsequent papers that are to follow the present one.

The physicist's point of view has been somewhat emphasized. Some new points and results which naturally arise in such a discussion are given in the paper in their proper place and could hardly be conveniently summarized here.

This study in part was undertaken while at Cambridge, and it is a pleasure to express my grateful thanks to Professor R. H. Fowler and Professor E. A. Milne (Oxford) for their kind interest and many valuable suggestions. To professor M. N. Saha I am as ever grateful for the kind and continued interest that he has taken in my work.

§1. When we observe a star, we see a mass of material radiating in space. Its state appears to be constant in time.* For any star, there are, in principle, three "observables"—its "luminosity" L (which is the energy radiated per second),** its mass M and its radius $r_1$. Actually the radius has been determined directly, i.e., by measurement of the angular diameter and the parallax (which gives the distance of the star) in only a very few cases. But from a study of the stellar spectra, as interpreted by the theory of thermal ionization, the "effective temperature" $T_e$ has been determined for many stars;*** the effective temperature being related to the radius $r_1$ according to the well-known relation $L = \pi a c r_1{}^2 T_e{}^4$, ($a$ being the Stefan's constant and its value is $7.62 \times 10^{-15}$ C. G. S. units).

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* Variable stars (Cepheids etc.) are excluded in the present discussion.

** The luminosity is usually stated in terms of the "absolute bolometric magnitude" $M_{bol}$ which is connected with L by the well-known relation $Log_{10} L = -0.4 M_{bol} + 35.52$. (L in ergs/second).

*** For some very bright stars the effective temperature has also been determined by measuring the energy in different parts of the spectrum. The star is assumed to radiate as a black body and $T_e$ is calculated by Planck's law. The values for $T_e$ obtained by these and other methods are in good agreement (Russell, Dugan and Stewart, Astronomy, volume II, page 753).

The different stars vary very considerably in luminosity among themselves – the range of variation being of the order of $10^8$.* The following table shows roughly the range of variation of the various physical quantities amongst different stars.

| | Luminosity L | Mass M | Radius $r_1$ | Effective temperature $T_e$ | Mean density | Energy radiated |
|---|---|---|---|---|---|---|
| Order of magnitude of the range of variation | $10^8$ | $10^2$ | $10^4$ | 10 (From 3,000 to 30,000 deg.) | $10^{12}$ (From $10^{-7}$ to $10^5$ grm./c.c.) | $10^6$ (From $10^{-2}$ to $10^4$ erg./grm. sec.) |

It is now well known from the researches of Eddington and those of others that there exist correlations between the three observables L, M, and $T_e$. These correlations are perhaps best exhibited by plotting Log L, Log M, and Log $T_e$ in a three-dimensional figure. The representative points of the stars are not distributed at random, but are very markedly localized in definite regions. This is shown (idealized) in figure 1. Speaking very roughly:

(i) The stars all lie in the diagonal plane ABCD (the white dwarfs are an exception; they possess for a given mass a much smaller luminosity than other stars of the same mass); and further, (ii) in this diagonal plane the stars generally lie *scattered* about the two diagonals.

The correlation (i) between mass and luminosity was first formulated by Eddington, and is called the "mass-luminosity law;" the correlation (ii) between luminosity and effective temperature is due to Hertzsprung and Russell. This relation is shown more significantly when Log $r_1$ is plotted against Log L (see, Milne, Halley Lecture, 1933).

* For Rigel $\beta$ orionis– the brightest star known–L is 14,000 times that for the Sun, whereas for $\alpha$-Proxima Centauri—which is probably the faintest known star—L is only 1/11,000 that for the Sun ; thus showing a range of variation of the order of $10^9$ (Russell, Dugan and Stewart, Astronomy, volume II, page 635).
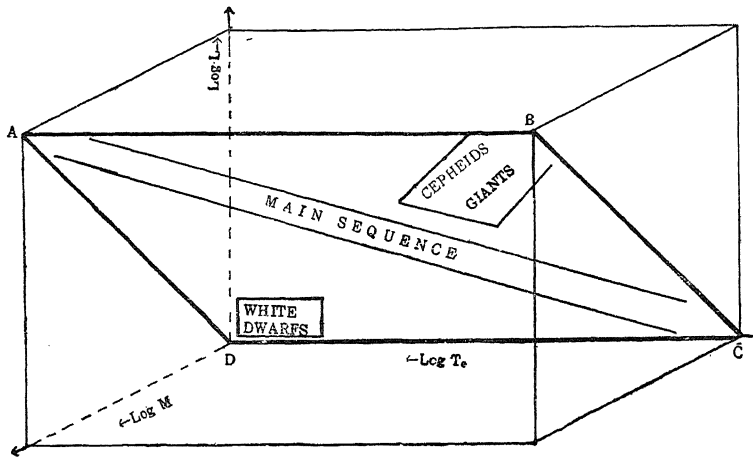
Fig. 1

These are the two fundamental relations which theoretical astrophysics has to explain.

The researches of Eddington, which on certain assumptions (the chief being that the star is entirely made of "classical" perfect gas) explained the "mass-luminosity-law," are now well known. The theory, however, was unable to offer any satisfying explanation of the "Russell-diagram." Milne, in his new attack on the problem of stellar structure, has obtained results which show the mass-luminosity law in a new light and afford at any rate a first clue towards the explanation of the broad features of the "Russell-diagram." However, for the sake of brevity (and perhaps also for clarity), we shall not follow here the line of historical development.

Ideally, the fundamental problem of stellar structure could be formulated thus :

For a given star of mass M (which is a spherically symmetrical aggregate of matter, calculate as to what will be (*i*) the luminosity (or luminosities) $L$; and (*ii*) the radius (or radii) $r_1$, making use of the following facts* known by observation :

(*i*) The star is in mechanical equilibrium because its state remains constant in time (for millions of years or longer);**

* See in this connection Milne, M. N. 90, 18, 1929.

** It is always understood that variable stars are excluded in the present discussion.

(*ii*) its outer layers are gaseous (in the sense of the " classical" perfect gas) as follows from the observed spectra; and

(*iii*) its outer layers are in "radiative equilibrium." This is known from direct observation only in the case of the sun (from the observed variation of brightness over the solar disc), but it is plausible to assume it for all stars.

*Equations of the Problem.*—We now enumerate the fundamental equations of the problem :—

1. The equation of mechanical equilibrium is

$$\frac{dp}{dr} + \frac{dp_r}{dr} = -\frac{GM(r)}{r^2}\rho \tag{1}$$

where $p_r$ is the radiation pressure $(p_r = \frac{1}{3}aT^4)$, $p$ the gas pressure, $\rho$ the density and $M(r)$ the mass enclosed within radius $r$. G is the gravitation constant.

Again we have*
$$\frac{dM(r)}{dr} = 4\pi r^2\rho. \tag{2}$$

2. *The equations of heat flow and "heat equilibrium."*—The flow of heat is due to

(*i*) radiation,
(*ii*) conduction,
and (*iii*) convection.

It is usual in the investigations of stellar structure to assume that the convective flow is negligible.** Further, as shown by the author,[5] conductive flow is very small (when compared to radiative flow) in non-degenerate matter, but it is predominant when the degeneracy is intense.

If $H_r$ denotes the net outward flow (per unit area and time) due to radiation, then

$$H_r = -\frac{c}{\kappa\rho}\frac{dp_r}{dr} = -\lambda_r\frac{dT}{dr} \tag{3$^1$}$$

where $\kappa$ is the radiative opacity and $\lambda_r$ the "radiational conductivity" $\left(\lambda_r = \frac{4acT^3}{3\kappa\rho}\right)$. The heat flow due to conduction is

$$H_c = -\lambda\frac{dT}{dt}$$

$\lambda$ being the thermal conductivity.

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*This may be called the equation of the "conservation of mass."

**This assumption has no strict physical justification. Rosseland (*M. N.* **89**, 49, 192. *Zs. f. Astrophysik*, 4, 255, 1932) has often emphasized the importance of convection in stellar problems. However, the inclusion of convection would too much complicate the problem mathematically.

Combining these two we have

$$H = H_r + H_c = - (\lambda_r + \lambda) \frac{dT}{dr} = - \frac{c}{\kappa'\rho} \frac{dp_r}{dr} \qquad (3^{11})$$

Therefore,

$$\frac{c}{\kappa'\rho} = (\lambda_r + \lambda)/\tfrac{4}{3} aT^3 = \frac{\lambda r}{\tfrac{4}{3}aT^3} (1 + \lambda/\lambda r)$$

or

$$\frac{c}{\kappa'\rho} = \frac{c}{\kappa\rho} (1 + \lambda/\lambda r)$$

and hence

$$\kappa' = \frac{\kappa}{1 + \lambda/\lambda r}$$

where $\kappa'$ is called the " *effective opacity.*"

The equation $(3^{11})$ is identical with $(3^1)$ except that the radiative opacity $\kappa$ is replaced by the effective opacity $\kappa'$. In the sequel, we shall usually drop the dash of $\kappa'$.

If L $(r) = 4\pi r^2$H, i.e., L$(r)$ is the net flux of heat crossing the sphere of radius $r$ in an outward direction, then from $(3^{11})$

$$\frac{dp_r}{dr} = \frac{\kappa L(r)}{4\pi c r^2} \rho \qquad (3)$$

The equation of 'Heat equilibrium' is obviously

$$\frac{dL(r)}{dr} = \frac{d}{dr} (4\pi r^2 H) = 4\pi r^2 \rho \varepsilon. \qquad (4)$$

where $\varepsilon$ is the heat liberated per second per gramme in the material situated at radius $r$.

Little (or rather nothing) is known about the actual process of energy-generation that operates in the stellar interiors. The energy-generating process can be of various types. One may classify them as follows*:

(*a*)  The rate of energy-generation is independent of the physical state** of the material, i.e., is a function of only C, where C is a parameter depending on the atomic composition of the material: $\varepsilon = \varepsilon$ (C).

(*b*)  The rate of energy-generation depends on C as well as the physical state** of the material, i.e., $\varepsilon = \varepsilon$ ($\rho$, T; C).

(*c*)  When the energy-generating process is in "temperature-equilibrium," then the forward reaction leading to energy-evolution and the reverse reaction leading to energy-absorption will be both proceeding simultaneously (and in fact, if the system be an enclosed one—thermally insulated—they both will

*See in this connection Note I at the end of the paper.

**This holds for the range of densities and temperatures that be under consideration; for example, the energy generation by radioactive disintegration which ordinarily is of type (*a*) would very probably be of type (*b*) or (*c*) for very high temperatures of the order of $10^9$ degrees or higher.

proceed at exactly the same rate). For a process of this type "the energy-gener-
ation originates as an effect of the natural 'cooling' of the star by surface
radiation to space; this causes adjustments in the interior which result in the
liberation of energy by the slight excess of the reversible reaction going on in
the direction encouraged by cooling."[6] The formula for ε will involve
$\frac{dT}{dt}$ besides the physical parameters and C: $\varepsilon = \varepsilon\ (\rho,\ T,\ C,\ \frac{dT}{dt})$.

(d) *Gravitational Contraction.*—As the star contracts, gravitational poten-
tial energy will be liberated for the star as a whole. However, for a given
element of the mass, we cannot in the general case (where the law of internal
distribution of density is changing as the star contracts) even fix the sign of
the work done by gravity.

[For a perfect-gas star the energy evolved in any given element during
homologous contraction under gravity is proportional to the temperature
of that element.]

(e) *Nuclear β-ray capture and re-emission.*—Bohr[7] has recently drawn
attention to the possibility of a far-reaching process involving a renunciation
of the law of conservation of energy "If, in a collision process, an electron
could attach itself to a nucleus with loss of its mechanical individuality, and
subsequently be recreated as a β-ray (with the nucleus falling back to its
initial state before the electron capture), we should find that the energy of
this β-ray would generally differ from that of the original electron." This
would imply a renunciation of the very idea of energy conservation.* Thus
under some suitable (but yet unknown) conditions it may be possible for
an assembly of electrons and atomic nuclei to *create* energy (for an indefinite
time).[8]

If the possibility of this process were definitely established,** it would
have revolutionary consequences on the whole problem of stellar evolution.

After this digression we revert again to the fundamental equations of the
problem. To the above equations we add two more. A knowledge of the
physics of matter at high temperatures and densities would give us

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*To quote again from Bohr: "At the present stage of the atomic theory, however, we
may say that we have no argument, either empirical or theoretical, for upholding the energy-
principle in the case of β-ray disintegrations, and are even led to complications and difficulties
in trying to do so."

**The recent great developments in the production of high voltages may also eventually
lead to an investigation of the above process. An examination of the energy distribution of
an intense beam of (artificially produced) β-rays scattered by atomic nuclei would reveal the
presence of this process, if it occurred.

(i)   the 'equation of state' connecting $p$, $\rho$, and T, i.e., $p = f\,(\rho, \text{T}; \text{C})$,

(ii)   the equation expressing the opacity $\kappa$ in the terms of $\rho$, and T, i.e., $\kappa = \kappa\,(\rho, \text{T}; \text{C})$,

where C, as before, is the parameter depending on the atomic composition of the material.

Thus, the fundamental equations of the problem are

$$\frac{dp}{dr} + \frac{dp_{\text{r}}}{dr} = -\frac{\text{GM}\,(r)}{r^2}\,\rho \qquad (i)$$

$$\frac{dp_{\text{r}}}{dr} = -\frac{\kappa \text{L}(r)}{4\pi c r^2}\,\rho \qquad (ii)$$

$$\frac{d\text{M}(r)}{dr} = 4\pi r^2 \rho \qquad (iii)$$

$$\frac{d\text{L}(r)}{dr} = 4\pi r^2 \rho \epsilon \qquad (iv)$$

$$p = f\,(\rho, \text{T}; \text{C}) \qquad (v)$$

$$\kappa = \kappa(\rho, \text{T}; \text{C}) \qquad (vi)$$

and in the general case

$$\epsilon = \epsilon\left(\rho, \text{T}; \frac{d\text{T}}{dt}; \text{C}\right) \qquad (vii)$$

The boundary conditions usual* in this problem are

(i)   $\left.\begin{array}{l} \rho \to 0 \\ \text{T} \to 0 \end{array}\right\}$ as $r \to r_1$ ($r_1$ is the radius of the star),

and        (ii)   $\left.\begin{array}{l} \text{M}(r) \to 0 \\ \text{L}(r) \to 0 \end{array}\right\}$ as $r \to 0$.

It is of interest to note in this connection a very important theorem due to Vogt and Russell[9] which follows at once from (a mere inspection of) the above system of equations and boundary conditions. The theorem states that: Stars of fixed atomic composition and for which the process of energy-generation is of type (a) or (b) above, must exhibit not only an exact relation connecting

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*Milne has recently examined (*Zs. f. Astrophysik*, **4**, 75, 1932) the Schwarzschild boundary condition $\text{T} \to \{\sqrt{\tfrac{3}{4}}\}^{\frac{1}{4}}\,\text{T}_e$ as $r \to r_1$; and has obtained new and interesting results. However, we are not concerned with them here.

mass and luminosity, but similar exact relations between mass and radius, radius and effective temperature, and any other pair of their macroscopic properties.*

Now, in the Russell diagram connecting L and $T_e$, the stars—particularly the *giants* and the *supergiants*—are scattered so widely that there is obviously no hope of fitting all points on a simple curve as required by the above theorem. It may therefore be concluded, that either

(i) the stars actually differ in chemical composition—atoms of various kinds being present in different proportions, either in the stars as a whole or from part to part of them,

or (ii) the energy-generating process is not of type (*a*) or (*b*), i.e., is not determined completely by $\rho$, T, and C,

[or both (i) and (ii) hold].

To a first approximation $p$ and $\kappa$ depend on C in only so far as the atomic composition affects the mean molecular weight $\mu$ (and generally under the conditions in the stellar interior $\mu$ is markedly sensitive only to the relative proportion of hydrogen, the proportion of other elements not affecting it very seriously). As regards $\varepsilon$, we can say nothing as to how it will depend on C. Further, as remarked before, $\varepsilon$ will in general depend not only on $\rho$, T, and C, but also on $\frac{dT}{dt}$ (i.e., the specification of $\varepsilon$ will not be complete unless we are also given the initial distribution of temperature inside the star—say at time $t_0$). Thus at the present stage it does not seem possible to specify the law of stellar energy-generation. In fact, progress in this direction is dependent not only on the advance in nuclear physics, but also primarily on our acquiring some definite knowledge regarding the order of temperatures and densities in the stellar interiors,** for only then is it possible to decide as to the type of the energy-generating process*** operative in the stellar interiors. *If this process be of type (c) or (d), then it will (essentially) be a problem for astrophysics alone to solve.*

Because of these considerations, it seems necessary to reformulate the fundamental problem (mentioned at the beginning of this section) in such a way that its solution does not depend on any theory of energy-

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*The assumption of fixed composition (i.e., C fixed) and the limitation of the type of the energy-generating process to (*a*) or (*b*) means that $p$, $\kappa$ and $\varepsilon$ are definite functions of $\rho$ and T and do not involve any other arbitrary parameters.

**The current theories of stellar structure give widely different results.

***The different types of possible processes are mentioned above.

F. 2

generation.* Then, by comparing the solutions so obtained with the observed properties of stars, it would finally be possible to gain an "insight" regarding the mechanism of energy-generation.

§2. Following Milne, the problem is stated thus:

A star is observed to possess mass M and luminosity L; what are the possible steady-state configurations of spherically-symmetrical aggregates of matter possessing this mass M and luminosity L ?

"To solve this problem we require a knowledge of the different phases which matter at a high temperature is capable of assuming. These phases include the "classical" perfect-gas and the degenerate-gas, both of them in the form either predominantly non-relativistic or predominantly relativistic; there may be, and probably are, other phases which are not yet known to us. The solution to the problem consists in enumerating in turn all the one-phase systems, the two-phase systems, the three-phase systems, and so on, consistent with the specification (L, M). L and M are selector variables, defining the configurations under discussion. When the enumeration has been completed as far as our present knowledge of different phases permits, comparison of the radius of the observed star (L, M) with the radii of the constructed configurations (L, M) will enable the state of the star to be diagnosed. If our knowledge of the different possible phases is complete, the constructed configurations must include amongst their number the actual configuration of the observed star (L, M)." (Milne, M. N., **92**, 612, 1932.)

The above programme requires no knowledge of the process of energy-generation.

So far, this programme has been carried out under some rather stringent simplifying assumptions for only one-phase gaseous configurations (Eddington) and two-phase configurations with gaseous envelope and (non-relativistic) degenerate core.[1] We now proceed to a brief consideration of these investigations.

*Equations of the Problem.*—

$$\frac{dp}{dr} + \frac{dp_r}{dr} = - \frac{GM(r)}{r^2} \rho \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (5)$$

*The problem, therefore, can no longer be to calculate L for a star of given M, but to treat L, M, as independent variables and calculate all possible radii for given L, M,

$$\frac{dp_r}{dr} = - \frac{\kappa L(r)}{4\pi c r^2}\rho \tag{6}$$

$$\frac{dM(r)}{dr} = 4\pi r^2 \rho \tag{7}$$

The boundary conditions are

$\rho \to 0$, $\quad T \to 0$ $\qquad$ as $r \to r_1$, (the radius of the star)

and $\qquad$ M$(r) \to 0$ $\qquad$ as $r \to 0$.

These equations have been already mentioned previously. From (5) and (6), we have

$$\frac{dp}{dr} = - \frac{GM(r)}{r^2}\rho \left\{ 1 - \frac{\kappa L(r)}{4\pi cG M(r)} \right\} \tag{8}$$

Assuming that

(i) $\kappa$ is constant, though not necessarily the same constant in each phase,

and (ii) L$(r)/$M$(r)$ is constant $=$ L/M,

$$\frac{dp}{dr} = - \frac{G M(r)}{r^2}\rho\beta$$

where $\qquad\qquad\qquad \beta = 1 - \frac{\kappa L}{4\pi cGM}.$

These two assumptions are made for mathematical simplification.* Their usefulness resides in the circumstance that possible configurations can then be very largely worked out in full and that these may be used to yield insight into the nature of configurations for other laws of opacity and other (energy-generating) source-distributions. The "standard-model" is intended not to represent the stars in Nature, but to throw light on their structure.**

In the gaseous envelope

$$p = \frac{k}{\mu m_H}\rho\, T, \quad \kappa = \kappa_1; \quad \beta_1 = 1 - \frac{\kappa_1 L}{4\pi cGM} \tag{9}$$

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* Under these conditions, the three equations (5), (6) and (7) reduce to a single second order differential equation—the Emden equation.

** A star is said to be built on the "standard-model" when the above two conditions (i.e., L$(r)/$M$(r) =$ L/M ; $k =$ constant for each phase) are satisfied.

and in the (non-relativistic) degenerate phase

$$p = \frac{K\rho^{5/3}}{\mu^{5/3}} \; ; \; \kappa = \kappa_2 \; ; \quad \beta_2 = 1 - \frac{\kappa_2 L}{4\pi c G M} \tag{10}$$

where

$$K = \frac{8\pi h^2}{15m} \left( \frac{3}{8\pi m_H} \right)^{\frac{5}{3}}.$$

*The pressure integrals.*—By division of (5) and (6) we have

$$\frac{dp}{dp_r} = \frac{dp}{d(\frac{1}{3}a T^4)} = \frac{4\pi c G M}{\kappa L} - 1$$

In any interval in which $\kappa$ is constant, this integrates in the form

$$p = \frac{1}{3} a T^4 \left\{ \frac{4\pi c G M}{\kappa L} - 1 \right\} + D \tag{11}$$

where D is constant in the interval. D changes discontinuously from one constant value to another when $\kappa$ changes.

Let $D_1$ be the value of D in the " classical " gas phase and $D_2$ its value in the degenerate phase   Using the boundary conditions

$$\rho \to 0, \; T \to 0 \; \text{as} \; r \to r_1,$$

we find that $D_1 = 0$ and

$$p = \left\{ \frac{(k/\mu m_H)^4}{\frac{1}{3}a} \; \frac{1 - \beta_1}{\beta_1} \right\}^{\frac{1}{3}} \rho^{\frac{4}{3}} = \triangle_1 \rho^{\frac{4}{3}} \tag{12}$$

where $\triangle_1$ is a constant.

Thus in the gaseous as well as the degenerate phase, $p$ is connected with $\rho$ by a relation of the form

$$p = \triangle^{\gamma} \tag{13}$$

where $\triangle$ and $\gamma$ are constants (different for each phase).

*Reduction to Emden's Equation.*—From (5), (8) and (13) we obtain

$$\frac{\triangle}{r^2}\frac{d}{dr}\left(\frac{r^2}{\rho}\frac{d\rho^\gamma}{dr}\right) = -4\pi G\beta\rho \tag{14}$$

Further, on substituting $\rho = \lambda\Theta^n$ where $\lambda$ is arbitrary, we have

$$\frac{n\gamma\triangle\lambda^{\gamma-2}}{r^2}\frac{d}{dr}\left(\frac{r^2\Theta^{n\gamma-1}}{\Theta^n}\frac{d\Theta}{dr}\right) = -4\pi G\beta\Theta^n$$

Choosing $n$ such that

$$n = n\gamma - 1 \qquad \text{i e.} \quad n = \frac{1}{\gamma-1} \text{ or } \gamma = 1 + \frac{1}{n}$$

we have $\qquad \dfrac{(n+1)\triangle\lambda^{\frac{1}{n}-1}}{r^2}\dfrac{d}{dr}\left(r^2\dfrac{d\Theta}{dr}\right) = -4\pi G\beta\Theta^n$

Substituting $\qquad r = \xi\left\{\dfrac{(n+1)\triangle}{4\pi G\beta\lambda^{1-\frac{1}{n}}}\right\}^{\frac{1}{2}}$ \tag{15}

we obtain the standard form

$$\frac{1}{\xi^2}\frac{d}{d\xi}\left(\xi^2\frac{d\Theta}{d\xi}\right) + \Theta^n = 0 \tag{16}$$

($n$ is called the index of the Emden's equation).

Further from (8)

$$\mathrm{M}(r) = -\frac{r^2}{G\beta\rho}\frac{dp}{dr} = -\frac{\lambda^{\frac{3-n}{2n}}}{2\pi^{\frac{1}{2}}}\left[\frac{(n+1)\triangle}{G\beta}\right]^{\frac{3}{2}}\xi^2\frac{d\Theta}{d\xi} \tag{17}$$

By substituting the proper values for $\triangle$ and $\gamma = 1 + \dfrac{1}{n}$, we at once obtain for the *gaseous* phase,

$$\frac{1}{\xi^2} \frac{d}{d\xi}\left(\xi^2 \frac{d\theta}{d\xi}\right) + \theta^3 = 0 \tag{18}$$

$$\rho = \lambda_1 \theta^3 \tag{19}$$

$$r = \frac{\xi}{\lambda_1^{\frac{1}{3}}}\left[\frac{(k/\mu m_{\mathrm{H}})^4}{\frac{1}{3}a} \frac{1-\beta_1}{\beta_1^4}\right]\frac{1}{(\pi G)^{\frac{1}{2}}} \tag{20}$$

$$\mathrm{M}(r) = -\left[\frac{16\,(k/\mu m_{\mathrm{H}})^4}{\pi^{\frac{1}{3}}a G^3}\frac{1-\beta_1}{\beta_1^4}\right]^{\frac{1}{2}}\xi^2 \frac{d\theta}{d\xi} \tag{21}$$

where $\lambda_1$ is so far undetermined.

It follows that, that solution of (18) is required for which putting $\mathrm{M}(r) = \mathrm{M}$ in (21), at $\xi = \xi_1$, we must have

$$\theta = 0, \qquad \omega_3 \equiv -\,\xi_1^2\left(\frac{d\theta}{d\xi}\right)_{\xi=\xi_1} = \mathrm{C}^{-\frac{1}{2}}$$

where

$$\mathrm{C} = \frac{16(k/m_{\mathrm{H}})^4}{\pi^{\frac{1}{3}}a\,G^3 M^2}\frac{1-\beta_1}{\mu^4 \beta_1^4} \tag{22}$$

and $\xi_1$ is arbitrary. The solution to be selected in the gas-zone thus depends solely on the physical properties in the gas-zone. If $f(\xi)$ is a solution of (18) vanishing at $\xi = \xi_0$ and satisfying $\omega_3 = \mathrm{C}^{-\frac{1}{2}}$, then

$$\theta = \mathrm{A}\,f(\mathrm{A}\xi)$$

is the solution required where $\mathrm{A}\xi_1 = \xi_0$.

For the *degenerate* phase, we have

$$\frac{1}{\eta^2} \frac{d}{d\eta}\left(\eta^2 \frac{d\psi}{d\eta}\right) + \psi^{\frac{3}{2}} = 0 \tag{23}$$

$$\rho = \lambda_2 \psi^{\frac{3}{2}} \tag{24}$$

$$r = \frac{\eta}{\lambda_2^{\frac{1}{6}}}\left[\frac{5K}{8\pi G\beta_2\mu^{\frac{5}{3}}}\right]^{\frac{1}{2}} \tag{25}$$

$$M(r) = -\frac{\lambda_2^{\frac{1}{2}}}{4(2\pi)^{\frac{1}{2}}}\left[\frac{5K}{G\beta_2\mu^{\frac{5}{3}}}\right]^{\frac{3}{2}}\eta^2 \frac{d\psi}{d\eta} \tag{26}$$

where $\lambda_2$ is so far undetermined.

Before proceeding further, we may just note certain well-known properties of Emden's equation.

*Proportion of Emden's Equation*[*].—Let $\theta = f(\xi)$ be a solution of Emden's equation of index $n$, vanishing at $\xi = \xi_0$. Then $\xi = \xi_1$ is the corresponding zero of the associated solution

$$\theta = A^{\frac{2}{n-1}} f(A\xi), \quad \text{if } A\xi_1 = \xi_0. \tag{27}$$

The value of
$$-\xi_1^{\frac{n+1}{n-1}}\left[\frac{d\theta}{d\xi}\right]_{\xi=\xi_1,} \tag{28}$$

for any assigned member A of the family $\theta = A^{\frac{2}{n-1}} f(A\xi)$ is independent of the choice of A, for it is equal to

$$-\xi_0^{\frac{n+1}{n-1}} f'(\xi_0) \tag{29}$$

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[*] These are here reproduced from Milne [*] *loc. cit.* page 618.

This is therefore a characteristic of the family, and its value may be taken to be the second arbitrary constant in the general solution. Denoting this constant by $\omega_n$, the general solution may be written

$$\theta = A^{\frac{2}{n-1}} f(A\xi; \omega_n) \tag{30}$$

The value of $\omega_n$ identifies the homologous family under consideration.

It is known from the researches of Fowler and others that corresponding to an assigned zero $\xi = \xi_1$ of $\theta$, for $\xi > 0$ there exists a critical $\omega^0{}_n$ of $\omega_n$ such that:

for $\omega_n = \omega_n{}^0$, $\theta(\xi) \to$ a finite limit as $\xi \to 0$ and $\theta(\xi)$ has no zeros in $0 \leq \xi < \xi_1$;

for $\omega_n < \omega_n{}^0$, $\theta(\xi) \to \infty$ as $\xi \to 0$ and remains positive in $0 \leq \xi < \xi_1$;

for $\omega_n > \omega_n{}^0$, $\theta(\xi)$ rises to a maximum as $\xi$ decreases from $\xi = \xi_1$ and $\theta(\xi)$ then decreases to a zero lying in $(0, \xi_1)$.

There exists likewise a monotonic sequence of critical values $\omega_n{}^1$ $\omega_n{}^2$ .... $\omega_n{}^r$ . . . . such that for $\omega_n = \omega_n{}^{(r)}$, $\theta(\xi) \to$ a finite limit as $\xi \to 0$ and $\theta(\xi)$ has $r$ zeros in $0 \leq \xi < \xi_1$.

When $\omega_n = \omega_n{}^0$, let $\theta_0$ be the positive value to which $\theta$ tends as $\xi \to 0$, for any assigned value of A.

Then we have     $\theta_0 = A^{\frac{2}{n-1}} f(0; \omega_n{}^0)$ $\qquad$ (31)

whence     $\xi_1^{\frac{2}{n-1}} \theta_0 = \xi_0^{\frac{2}{n-1}} f(0; \omega_n{}^0)$ $\qquad$ (32)

Thus $\xi_1^{\frac{2}{n-1}} \theta_0$ is the same for all members A of the homologous family $\omega_n = \omega_n{}^0$. We shall denote it by $\sigma_n$. We just note that[10]

$$\omega_3{}^0 = -\xi_0{}^2 \, f'\,(\xi_0;\,\omega^0{}_3)\ = 2{\cdot}0181;\ \omega^0{}_{\frac{3}{2}} = -\,\eta_0{}^5 \, \phi'\,(\eta_0;\,\omega^0{}_{\frac{3}{2}}) = 132{\cdot}39$$

$$\sigma_3 = \xi_0 f\,(0;\,\omega_3{}^0)\ = 6{\cdot}8969;\ \sigma_{\frac{3}{2}} = \eta_0{}^4 d\,(0;\,\omega^0{}_{\frac{3}{2}}) = 178{\cdot}23$$

Following the terminology of Milne, a solution $A^{\frac{2}{n-1}} f\,(A\xi;\,\omega_n)$ of

Emden's equation of index $n$, will be said to be of

"Collapsed" type if $\quad \omega_n > \omega_n{}^0$

"Emden" type if $\quad \omega_n = \omega_n{}^0$

and "Centrally Condensed" type if $\quad \omega_n < \omega_n{}^0$.

§3. *One-Phase Gaseous Configurations.*—As in this case we are assuming the perfect gas phase to extend up to the centre of the star, the required solution of Emden's equation (index 3) must possess no singularity at the centre. The only such solution is the Emden solution $(\omega_3 = \omega_3{}^0)$.

Therefore, from equation (22) we obtain

$$(\omega_3{}^0)^{-2} = \left(\frac{1}{2{\cdot}0181}\right)^2 = \frac{16\,(k/\mu m_{\mathrm{H}})^4\,(1-\beta_1)}{\pi^{\frac{1}{3}}\alpha G^3 M^2 \beta_1{}^4} \tag{33}$$

Hence,

$$1-\beta_1 = 7{\cdot}82\ 10^{-70}\ \beta_1{}^4\ \mu^4 M^2$$

$$1-\beta_1 = 0{\cdot}050\ \beta_1{}^4 \left(\frac{M}{\odot}\right)^2 \left(\frac{\mu}{2{\cdot}1}\right)^4 \tag{34}*$$

where $\odot$ = mass of the sun.

Again we have $\qquad 1-\beta_1 = \dfrac{\kappa_1 L}{4\pi c G M}$

Taking (in accordance with Kramer's law),

$$\kappa_1 = \frac{\alpha_1\,\rho_c}{T_c{}^{\frac{7}{2}}}$$

Where $\alpha_1$ is a constant and $\rho_c$, $T_c$ are the central density and central temperature respectively, we have

$$1-\beta_1 = \frac{\alpha_1\,\rho_c}{T_c{}^{\frac{7}{2}}}\ \frac{L}{4\pi c G M}$$

* This is Eddington's famous quartic equation.

F. 3

Further from (11) we at once have

$$\frac{\rho_c}{\frac{1}{3} a T_c{}^3} = \frac{\beta_1}{1-\beta_1} \frac{\mu}{k/m_H}$$

and therefore

$$L = \frac{4\pi c G M}{\alpha_1} \frac{(1-\beta_1)^{\frac{13}{6}} (k/m_H)^{\frac{7}{6}} \rho_c{}^{\frac{1}{6}}}{(\frac{1}{3} a)^{\frac{7}{6}} \beta_1{}^{\frac{7}{6}} \mu^{\frac{7}{6}}} \tag{35}$$

From (19) and (20) and using the definition of $\sigma_3$ we find after a little reduction that

$$\rho_c = \frac{\sigma_3{}^3}{r_1{}^3 (\pi G)^{\frac{3}{2}}} \left[ \frac{(k/\mu m_H)^4}{\frac{1}{3} a} \frac{1-\beta_1}{\beta_1{}^4} \right]^{\frac{1}{2}} \tag{36}$$

Substituting this value of $\rho_c$ in (35) and eliminating M by using (33), we have

$$L = 16\pi^{\frac{1}{4}} \omega_3{}^0 \sigma_3{}^{\frac{1}{2}} \frac{(k/m_H)^{\frac{7}{2}}}{(\frac{1}{3} a)^{\frac{7}{4}}} \frac{c}{G^{\frac{3}{4}}} \frac{(1-\beta_1)^{\frac{11}{4}}}{\beta_1{}^{\frac{7}{2}} \mu^{\frac{7}{2}}} \frac{1}{(\alpha_1{}^2 r_1)^{\frac{1}{2}}} \tag{37}*$$

As from (34) $\beta_1$ is a function of $M\mu^2$, we can express (37) in the form —

$$r_1 = -\frac{\text{constant}}{(\alpha_1 L)^2} f (M\mu^2) \tag{38}$$

For any prescribed (L, M) the uniqueness of the predicted radius is in conflict with the "Russell-diagram."

Further, when the theoretical value of $\alpha_1$ is substituted in the formula and on the assumption that the stars do not contain a large proportion of hydrogen, the calculated value of $r_1$ comes out about a hundred times larger than the observed radius $r_1$ for any observed pair (M, L) selected from amongst the "ordinary" stars (i.e., not white dwarf stars)  However, on the hypothesis of "hydrogen-abundance" these difficulties can be removed[11]. We shall not enter into this explanation here, but proceed to the two-phase configurations**.

§4   *Two-phase Configurations.*—We now consider the two-phase configurations of the "generalised standard model" consisting of a gaseous envelope and (non-relativistic) degenerate core.

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*This is easily transformed in the  more usual form, $M_{Bol}$ = constant $- 3\cdot75$ Log $(1 - \beta_1)$ $- 3\cdot5$ log $M/\odot - 2$ log $\mu - \log T_e$. The effect of the last term is comparatively small so long as the effective temperature lies between about 3,000° to 25,000 degrees. This equation thus represents approximately (but not *exactly*) a relation between Mass and Luminosity.   This is Eddington's "Mass-Luminosity law."

** According to Stromgren different types of stars imply varying amounts of hydrogen, so that the "hydrogen-abundance" is simply an empirical parameter which can be adjusted to fit with certain feature of the Russell-diagram.

*Equations of Fit.*—Though the actual transition from the perfect gas envelope to the degenerate central region must occupy a certain zone, we may for convenience take the two regions to be separated by a definite surface of demarcation.

We shall now obtain the equations that define the position of this interface.

In the following derivation, however, *we do not restrict to this particular case (of gaseous envelope and non-relativistic degenerate central region) but obtain the " equations of fit " in their most general form.*

Let the interface occur at $r=r'$.

Outside $r=r'$ let the distribution of density be given by a solution of Emden's equation of index $n_1$, and inside $r=r'$ let it be given by a solution of Emden's equation of index $n_2$. The fit of the "$n_1$-distribution" on to the "$n_2$-distribution" must be made in such a way that the mass missing from the incomplete "$n_1$-distribution" must be actually found in the incomplete "$n_2$-distribution".

Approaching the interface from the " " $n_1$-phase we have by (13), (14) (15) and (17)

$$r' = \xi' \left[ \frac{(n_1+1)\,\triangle_1}{4\pi G\beta_1\,\lambda_1^{1-\frac{1}{n_1}}} \right]^{\frac{1}{2}} \tag{39}$$

$$M(r') = \frac{\lambda_1^{\frac{3-n_1}{2n_1}}}{2\pi^{\frac{1}{2}}} \left[ \frac{(n_1+1)\,\triangle_1}{G\beta_1} \right]^{\frac{3}{2}} \xi'^2 \left( \frac{d\theta}{d\xi} \right)_{\xi=\xi^1} \tag{40}$$

$$\rho_1' = \lambda_1[\theta(\xi')]^{n_1} \tag{41}$$

$$p' = \triangle_1\rho_1'^{\left(1+\frac{1}{n_1}\right)} \tag{42}$$

where $\rho_1'$ is the density at the interface (it being approached from the "$n_1-$ phase").

Approaching the interface from the "$n_2-$phase" we have similarly

$$r' = \eta' \left[ \frac{(n_2+1)\triangle_2}{4\pi G\beta_2\lambda_2^{1-\frac{1}{n_2}}} \right]^{\frac{1}{2}} \tag{43}$$

$$M(r') = \frac{\lambda_2^{\frac{3-n_2}{2n_2}}}{2\pi^{\frac{1}{2}}} \left[ \frac{(n_2+1)\,\triangle_2}{G\beta_2} \right]^{\frac{3}{2}} \eta'^2 \left( \frac{d\psi}{d\eta} \right)_{\eta=\eta'} \tag{44}$$

$$\rho'_2 = \lambda_2 \left[\psi(\eta')\right]^{n_2} \tag{45}$$

$$p' = \triangle_2 \rho_2'^{1+\frac{1}{n_2}} \tag{46}$$

If $f(\xi)$ be a solution of Emden's equation (index $n_1$), $f(\xi)$ vanishing at $\xi = \xi_0$, then $A^{\frac{2}{n_1-1}} f(A\xi)$ is an associated solution having its zero at $\xi_1 = \xi_0/A$. Writing $A\xi' = a$, we obtain after some reduction

$$r' = \rho_1'^{\frac{1-n_1}{2n_1}} \left[\frac{(n_1+1)\triangle_1}{4\pi G\beta_1}\right]^{\frac{1}{2}} a[f(a)]^{\frac{n_1-1}{2}} \tag{47}$$

$$M(r') = \frac{\rho_1'^{\frac{3-n_1}{2n_1}}}{2\pi^{\frac{1}{2}}} \left[\frac{(n_1+1)\triangle_1}{G\beta_1}\right]^{\frac{3}{2}} \frac{a^2 f'(a)}{[f(a)]^{\frac{3-n_1}{2}}} \tag{48}$$

Similarly if $\phi(\eta)$ be a solution of Emden's equation (index $n_2$), $\phi(\eta)$ vanishing at $\eta = \eta_0$, then $B^{\frac{2}{n_2-1}} \phi(B\eta)$ is an associated solution having its zero at $\eta_1 = \eta_0/B$. Writing $b = B\eta'$, we have corresponding to (47) and (48)

$$r' = \rho_2'^{\frac{1-n_2}{2n_2}} \left[\frac{(n_2+1)\triangle_2}{4\pi G\beta_2}\right]^{\frac{1}{2}} b [\phi(b)]^{\frac{n_2-1}{2}} \tag{49}$$

$$M(r') = \frac{\rho'_2^{\frac{3-n_2}{2n_2}}}{2\pi^{\frac{1}{2}}} \left[\frac{(n_2+1)\triangle_2}{G\beta_2}\right]^{\frac{3}{2}} \frac{b^2 \phi'(b)}{[\phi(b)]^{\frac{3-n_2}{2}}} \tag{50}$$

The conditions of fit are that the values of $M(r')$ and $r'$ given by (47), (48) and (49), (50) shall be equal. Equating the values (and noting that the pressure must be equal on both sides of the interface) we have

$$\frac{1}{\rho'_1{}^2}\left[\frac{n_1+1}{\beta_1}\right]^{\frac{3}{2}} \frac{a^2 f'(a)}{[f(a)]^{\frac{3-n_1}{2}}} = \frac{1}{\rho_2'{}^2}\left[\frac{n_2+1}{\beta_2}\right]^{\frac{3}{2}} \frac{b^2 \phi'(b)}{[\phi(b)]^{\frac{3-n_2}{2}}} \tag{51}$$

$$\frac{1}{\rho'_1}\left[\frac{n+1}{\beta_1}\right]^{\frac{1}{2}} a [f(a)]^{\frac{n_1-1}{2}} = \frac{1}{\rho'_2}\left[\frac{n_2+1}{\beta_2}\right]^{\frac{1}{2}} b [\phi(b)]^{\frac{n_2-1}{2}} \tag{52}$$

By combining these two equations, they may be thrown in the "canonical form"

$$\frac{n_1+1}{\rho'_1 \beta_1} \frac{af'(a)}{f(a)} = \frac{n_2+1}{\rho_2' \beta_2} \frac{b\phi'(b)}{\phi(b)} \tag{53}$$

$$\frac{a[f'(a)]^{n_1}}{\rho_1' f'(a)} = \frac{b\,[\phi(b)]^{n_2}}{\rho_2'\,\phi'(b)} \tag{54}$$

These are the "equations of fit" in their most general form.**

For the case of the gaseous envelope $(n_1 = 3)$ and (non-relativistic) degenerate interior $(n_2 = \frac{3}{2})$ the above equations reduce to

$$\frac{a\,[f'(a)]^3}{\rho_1' f'(a)} = \frac{b\,[\phi(b)]^{\frac{3}{2}}}{\rho_2'\,\phi'(b)} \tag{55}$$

$$\frac{af'(a)}{f(a)} = \left(\frac{\rho_1'}{\rho_2'}\right)\left(\frac{5}{8}\frac{\beta_1}{\beta_2}\right)\frac{b\phi'(b)}{\phi(b)} \tag{56}$$

Further we may note that

$$1 - \frac{a}{\xi_0} = \frac{\text{Thickness of gaseous envelope}}{\text{Radius of configuration}}. \tag{57}$$

Now from (15), after some algebra, we have for the total radius of the configuration

$$r_1 = \left(\frac{\rho_2'}{\rho_1'}\right)^{\frac{5}{3}}\frac{(\frac{1}{3}a)^{\frac{1}{6}}}{(\pi G)^{\frac{1}{2}}}\frac{K\xi_0 f(a)}{(k/m_H)^{\frac{2}{3}}\,\mu\,(1-\beta_1)^{\frac{1}{6}}\,\beta_1^{\frac{1}{3}}} \tag{58*}$$

This transforms by using (55) and (56) and after some reduction into,

$$r_1 = \frac{5\,K/\mu^{\frac{5}{3}}}{2^{\frac{7}{3}}\,\pi^{\frac{2}{3}}\,GM^{\frac{1}{3}}\,\beta_2}\,\frac{\xi_0}{a}\left[\frac{-\xi_0{}^2 f'(\xi_0)}{a^2 f'(a)}\,b^5\,\phi'(b)\right]^{\frac{1}{3}} \tag{59}$$

In the sequel we shall assume the density to be continuous at the interface $(\rho_1' = \rho_2')$.**

If $\rho'$ and $T'$ denote the interfacial values of $\rho$ and $T$, then

$$\frac{k\,\rho'\,T'}{\mu\,m_H} = \frac{K}{\mu^{\frac{5}{3}}}\,\rho'^{\frac{5}{3}} \tag{60}$$

Approaching the interface from the classical gas phase we have from (12)

$$\frac{k\,T'}{\mu m_H} = \left\{\frac{(k/\mu\,m_H)^4}{\frac{1}{3}a}\,\frac{1-\beta_1}{\beta_1}\right\}^{\frac{1}{3}}\rho'^{\frac{1}{3}} \tag{61}$$

Approaching it from the degenerate gas phase, we have from (11)

$$\frac{K\rho'^{\frac{5}{3}}}{\mu^{\frac{5}{3}}} = \frac{1}{3}\,a\,T'^4\,\frac{\beta_2}{1-\beta_2} + D_2 \tag{62}$$

* As before, the pressure of degenerate gas is equal to $\dfrac{K\rho^{5/3}}{\mu^{5/3}}$

** Milne has given the "equations of fit" for this case of $\rho_1' = \rho_2'$. They are given here without this limitation.

Thus we obtain from (60), (61) and (62)

$$T' = \frac{(k/m_H)^{\frac{5}{3}}}{(\frac{1}{3}a)^{\frac{2}{3}} K} \left( \frac{1-\beta_1}{\beta_1} \right)^{\frac{2}{3}} \tag{63}$$

$$\rho' = \frac{(k/m_H)^4}{\frac{1}{3} a K^3} \frac{1-\beta_1}{\beta_1} \mu \tag{64}$$

$$D_2 = \frac{(k/m_H)^{\frac{20}{3}}}{(\frac{1}{3}a)^{\frac{5}{3}} K^4} \frac{(1-\beta_1)^{\frac{5}{3}} (\beta_1-\beta_2)}{\beta_1^{\frac{8}{3}} (1-\beta_2)} \tag{65}$$

*The physical properties for the two phase configurations.*

The solution $f(\xi, \omega_3)$ to be selected in the envelope depends solely on the "observables" L, M and $\kappa_1$ as

$$\omega_3 = C^{-\frac{1}{2}} = \frac{16(k/m_H)^4}{\pi^{\frac{1}{3}} a G^3 M^2 \mu^4} \frac{1-\beta_1}{\beta_1^4}$$

and the solution $\phi(\eta, \omega_{\frac{3}{2}})$ must be the Emden-solution $(\omega_{\frac{3}{2}} - \omega^0_{\frac{3}{2}})$, because the non-relativistic degenerate phase is assumed to extend (in the physical sense) up to the centre.

From the equations already given, the formulæ for the various physical quantities – for example, the radius of the configuration, mean density, central temperature etc. — can be readily obtained. These can be expressed in terms of invariant form, $a/\xi_0$, $b/\eta_0$, $af(a)$, $b^4\phi(b)$, $-a^2f'(a)$, $-b^5\phi'(b)$, so as to be independent of the "normalisation" to the zeros $\xi_0$, $\eta_0$. The values of $a$ and $b$ are found by solving the two equations of fit.

As an illustration we derive the formula for the central temperature $T_c$. From (62) and (65)

$$\frac{K_{\rho c}^{\frac{5}{3}}}{\mu^{\frac{5}{3}}} = \frac{1}{3} a T^4_c \frac{\beta_2}{1-\beta_2} + \frac{(k/m_H)^{\frac{20}{3}}}{(\frac{1}{3}a)^{\frac{5}{3}} K^4} \frac{(1-\beta_1)^{\frac{5}{3}} (\beta_1-\beta_2)}{\beta_1^{\frac{8}{3}} (1-\beta_2)} \tag{66}$$

Now

$$\rho_c = \lambda_2 [\psi(o)]^{\frac{3}{2}} = \lambda_2 B^6 [\phi(o, \omega^0_{\frac{3}{2}})]^{\frac{3}{2}} \tag{67}$$

and

$$\rho' = \lambda_2 B^6 [\phi(b, \omega^0_{\frac{3}{2}})]^{\frac{3}{2}} \tag{68}$$

Therefore

$$\frac{\rho_c}{\rho'} = \frac{(\sigma_{\frac{3}{2}})^{\frac{3}{2}}}{[\eta_0^4 \phi(b)]^{\frac{3}{2}}} \tag{69}$$

Substituting from (64) for $\rho'$

$$\rho_c = \frac{(k/m_H)^4 \mu}{\frac{1}{3} a K^3} \frac{1-\beta_1}{\beta_1} \frac{[\sigma_{\frac{3}{2}}]^{\frac{3}{2}}}{[\eta_0^4 \phi(b)]^{\frac{3}{2}}} \tag{70}$$

Therefore

$$T_c = \frac{(k/m_H)^{\frac{5}{3}}}{(\frac{1}{3} a)^{\frac{2}{3}} K} \left( \frac{1-\beta_1}{\beta_1} \right)^{\frac{5}{12}} \left( \frac{1-\beta_2}{\beta_2} \right)^{\frac{1}{4}} \left[ \frac{\sigma_{\frac{3}{2}}}{\eta_0^4 \phi(b)} \right)^{\frac{5}{2}} - \frac{\beta_1-\beta_2}{\beta_1(1-\beta_2)} \right]^{\frac{1}{4}} \tag{71}$$

Owing to the existence of the equations of fit, transformations of this formula are possible. It may thus be thrown in the form

$$T_c = \left[ \frac{1-\beta_2}{\beta_2} \frac{K}{\frac{1}{3}a} \left( \frac{32}{125} \pi \frac{G^3 M^2}{K^3} [\sigma_2]^{\frac{3}{2}} \beta_2{}^3 \mu^4 \right)^{\frac{5}{3}} \left( \frac{-a^2 f'(a) (b/\eta_0)^3}{\xi_0{}^2 f'(\xi_0) b^5 \phi(b)} \right)^{\frac{10}{3}} \right.$$
$$\left. - \frac{(k/m_H)^{\frac{20}{3}}}{(\frac{1}{3}a)^{\frac{8}{3}} K^4} \frac{(1-\beta_1)^{\frac{5}{3}}}{\beta_1{}^{\frac{8}{3}}} \frac{(\beta_1-\beta_2)}{\beta_2} \right]^{\frac{1}{4}} \tag{72}$$

The formulæ for the other physical quantities are given in Milne's paper and are also tabulated in my paper[5], where their applications are considered.

The solutions of the equations of fit (for the two-phase configurations) will give $a$ and $b$ as functions of $\beta_1/\beta_2$ and $\omega_3$ (where $\omega_3$ depends only on M and $\beta_1$). From equation (57) we have

$$\frac{\text{Radius of degenerate core}}{\text{Radius of configuration}} = \frac{a}{\xi_0} = F(\omega_3, \beta_1/\beta_2)$$
$$= F(\beta_1, \beta_1/\beta_2, M). \tag{73}$$

where $F(\beta_1/\beta_2, \omega_3)$ is known when the equations of fit have been solved. Milne has obtained by graphical methods the solutions of the equations of fit for a few values of $\omega_3$ and has constructed curves for $a/\xi_0$, plotted against $\beta_1/\beta_2$ for constant $\omega_3$. These are shown in figure 2 reproduced from Milne's paper.

$$\text{Since} \qquad \beta_1/\beta_2 = \frac{1-\kappa_1}{1-\kappa_2} \frac{L/4\pi c \, GM}{L/4\pi c \, GM} = \frac{\beta_1}{1-\kappa_1/\kappa_2 (1-\beta_1)} \tag{74}$$

$\frac{a}{\xi_0}$ can be expressed as $F(\beta_1/\beta_2, M, \kappa_1/\kappa_2)$. Thus corresponding to any point $(\beta_1/\beta_2, \omega_3)$ in the figure, it is possible to find M for any given value of $\kappa_1/\kappa_2$. By joining up points of constant mass, we can describe on the diagram curves of constant mass M, for any given $\kappa_1/\kappa_2$, and so exhibit all the possible two-phase configurations of a given mass M. In order to gain any insight into these results for any value of $\kappa_1/\kappa_2$, Milne has examined in detail the limiting case of zero opacity in the core ($\kappa_2/\kappa_1 \sim 0$). And that this case has physical justification is easily seen as follows:—

*Approximation for $\kappa_2/\kappa_1$.* As an approximation, we shall take $\kappa_1$ the opacity in the envelope to be equal to the non-degenerate value at the interface, i e., according to Kramer's law we take[5].

$$\kappa_1 = 4\cdot23 \; 10^{23} \frac{\rho'}{T^{\frac{7}{2}}} \tag{75}$$

In the degenerate core, the heat flow would be predominantly by conduction[5] and so we shall take for $\kappa_2$ the value of the *effective opacity* (and not the pure radiative opacity) at the centre.

Now, as has been shown by the author,[5] the effective opacity is given by

$$\left(\begin{array}{c}\text{Effective opacity} \\ \text{at centre}\end{array}\right) = \left(\frac{\text{Radiative opacity } \kappa_2 \times \text{Radiational conductivity } \lambda_R}{\text{Thermal conductivity } \lambda}\right) \quad (76)$$

Therefore,

$$\frac{\kappa'_2}{\kappa_1} = \frac{\kappa_2 \text{ (centre)}}{\kappa_1 \text{ (interface)}}\left(\frac{\lambda_R}{\lambda}\right)_{\text{centre}}$$

As      $\kappa_2 \propto \dfrac{1}{T^2}$, and therefore $\kappa_2$ (interface) $> \kappa_2$ (centre) and    hence

$$\frac{\kappa'_2}{\kappa_1} < \frac{\kappa_2 \text{ (interface)}}{\kappa_1 \text{ (interface)}}\left[\frac{\lambda_R}{\lambda}\right]_{\text{centre}}$$

Substituting the values for $\kappa_2/\kappa_1$ and $\lambda_R/\lambda$ as given by equations (6) and (18) of my previous paper[5], we have

$$\frac{\kappa'_2}{\kappa_1} < \frac{6\cdot97}{A'_0} \cdot \frac{3\cdot88 \times 10^{-8} \, T_c I_1}{A_c^2} . \quad (77)$$

where $A_c$ is the value of the Sommerfeld degeneracy-discriminant at the centre, and $A_0'$ its value at the interface. The values of $I_1$ for different densities can be calculated from the formula given in the paper referred to and are tabulated therein.

At the interface the pressure given by the degenerate and the non-degenerate formulæ are equal,

$$\frac{K\rho'^{\frac{5}{3}}}{\mu^{\frac{5}{3}}} = \frac{kT'}{\mu m_H} \quad (78)$$

This gives by putting      $K = \dfrac{8\pi h^2}{15m}\left(\dfrac{3}{8\pi m_H}\right)^{\frac{5}{3}}$,

the value of $A_0 = 2\cdot97$ at the interface.

Therefore      $\dfrac{\kappa'_2}{\kappa_1} < \dfrac{9\cdot1 \times 10^{-8} \, T_c \, I_1}{A_c^2}$      (79)*

and hence when the degeneracy at the centre is intense, i.e., $A_c >> 1$, we can take

$$\frac{\kappa'_2}{\kappa_1} \sim 0.$$

* It may particularly be noted that this result essentially depends on our taking into account the conductive flow, i.e, on our using the "effective opacity", instead of the "radiative opacity."

As we are using non-relativistic statistics, the above formula is applicable as long as the relativistic effect is negligible and this is so provided $T << \dfrac{3\cdot57 \times 10^9}{A_c^{\frac{2}{3}}}$ : substituting    this    value

for $T_c$, $\kappa'_2/\kappa_1 << \dfrac{3\cdot30 \times 10^2 I_1}{A_c^{\frac{2}{3}}}$ .

*Properties of Mass Curves* for $\kappa'_2/\kappa_1 \sim 0$.—

We have in this case $\beta_1/\beta_2$ reduced to $\beta_1$. Some typical mass-curves are shown in the diagram. As we have already mentioned, a reasonable value for $\kappa_1$ is the value of the non-degenerate interfacial opacity. This gives

$$\kappa_1 = 10\cdot1 \ (M/L)^{\frac{4}{7}}$$

and $$1-\beta_1 = 4\cdot01 \ 10^{-4} \ (L/M)^{\frac{3}{7}}$$

The horizontal scale of $\beta_1$ may thus be regarded as a scale of $(L/M)^{\frac{3}{7}}$ in the negative direction. The point E corresponds to $L/M=0$ and the configurations for the largest possible value of $L/M$ occur in the region near the left-hand edge of the diagram.

Two types of mass-curves are seen in the figure. The mass-curve which separates the two types passes through the point A $(\beta_1 = \frac{4}{5}, \omega_3 = \omega_3{}^0)$, it is the curve $M = M_0$ where

$$\omega_3{}^0 = 2\cdot018 = \left\{ \frac{16(k/m_H)^4}{\pi^{\frac{1}{3}} a G^3 M_0{}^2} \ \frac{(1-\beta_1)}{\mu^4 \beta_1{}^4} \right\}^{-\frac{1}{2}}_{\beta_1 = \frac{4}{5}} \qquad \dots \quad \dots \quad (80)$$

$$M_0 = 2\cdot88 \odot \left( \frac{2\cdot1}{\mu} \right)^2 \qquad \dots \quad \dots \quad \dots \quad \dots \quad (81)$$

From an inspection of the diagram it follows that :—

(*i*) For $M \leq M_0$, all configurations which exist are of collapsed type $(\omega_3 > \omega_3{}^0)$ and $\beta_1$ necessarily lies between $\beta_1{}^0$, and unity, where $\frac{4}{5} < \beta_1{}^0 < 1$, $\beta_1{}^0$ being a function of $M$ given by

$$\omega_3{}^0 = \left[ \frac{16 \ k/m_H)^4}{\pi(\frac{1}{3}a)9 G^3 M^2} \ \frac{\cdot 1-\beta_1{}^0}{\mu^4(\beta_1{}^0)^4} \right]^{-\frac{1}{2}} \qquad \dots \quad \dots \quad (82)$$

(*ii*) For $M > M_0$, the configurations which exist are either collapsed $(\beta_1 > \beta_1{}^0)$ or centrally condensed.

These two-phase configurations constructed by Milne, possess many striking properties. Consider a typical mass curve such as for $M = 20 \odot$. For this curve, any ordinate not too far to the left of S'T' (T' is vertically below S') meets the mass-curve in two points S, T. Thus for any assigned value of $L/M$ exceeding that corresponding to the point T' (but not much exceeding it) and for the assigned mass M, there are two distinct configurations possible, of two different relctive core radii and accordingly two different external radii. Milne has suggested this phenomenon to be the counterpart of the existence in Nature of the two distinct giant M and B, O stars for large $L/M$. We thus at least gain some insight as to some features of the "Russell-diagram". We shall, however, not enter here into these and other details, but shall merely note the explanation of the 'mass luminosity law' as given by Milne.

F. 4
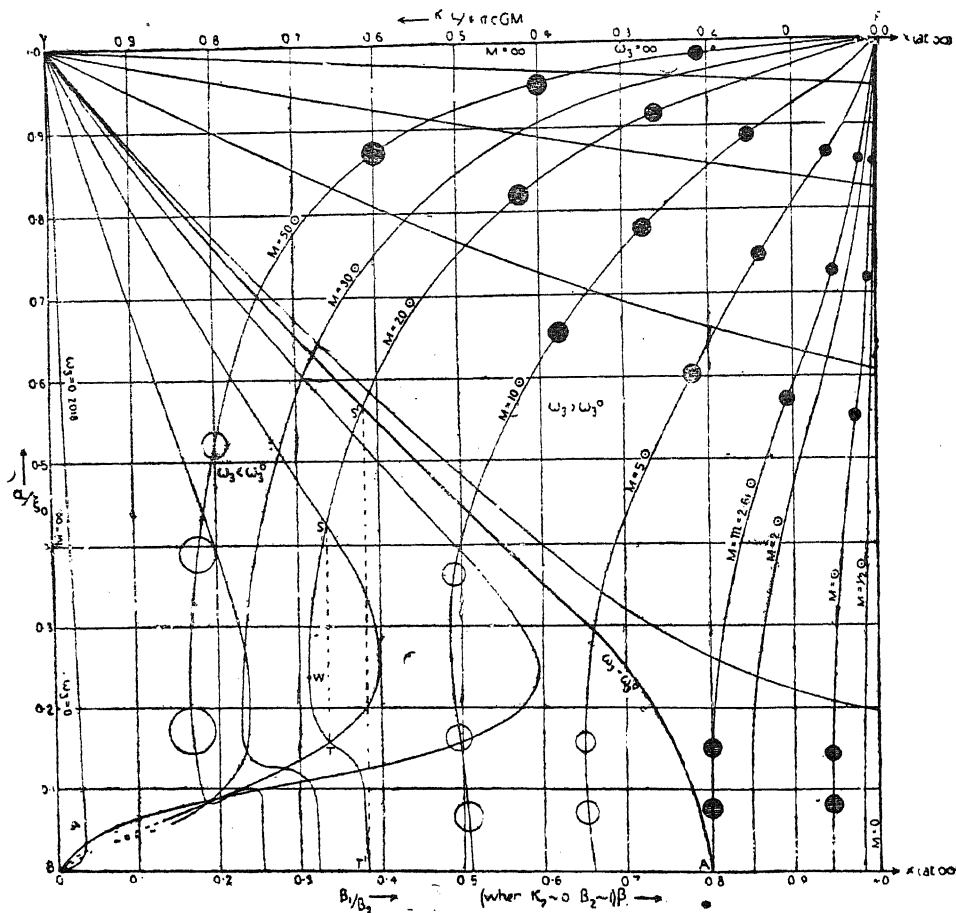
FIG. 2—"*Curves of relative core-radius $a/\xi_0$ plotted against $\beta_1/\beta_2$ for constant $\omega_3$. Also curves of $a/\xi_0$ against $\beta_1$ for constant mass* M *when* $\kappa_2 \sim 0$, $\beta_2 \sim 1$. *The locus* $\omega_3 = \omega_3{}^0$ *divides "centrally-condensed" configurations from "collapsed" configurations, and itself gives the quasi-diffuse configurations. The circles indicate qualitatively the external radii of the configuration; they are not drawn on a uniform radius-scale. Open circles denote "centrally-condensed" configurations, shaded circles "collapsed" configurations. Points such as W, represent configurations probably possessing Cepheid characteristics.*" [*From. Milne, M. N.* **92**, *630, 1932*].

We see from the figure that for $M > M_0$, centrally-condensed portions of the mass-curves depart only slightly from the vertical. It follows that L must lie between narrow limits, depending on M, for a centrally-condensed configuration to be possible. "If L lies above these limits, no configuration exists, and the system would either burst or cease to be a two-phase system. If L lies below them, the system is collapsed with a large relative core-radius. We thus see that for $M > M_0$, the configurations

which are centrally-condensed will exhibit an approximate, but not exact mass luminosity correlation.

When $M \leq M_0$, the lower parts of the mass-curves are also nearly vertical, so the smaller-cored collapsed configurations will also exhibit an approximate mass-luminosity correlation. Since the luminosity is in each case given approximately by

$$L \doteq \frac{4\pi c GM \, (1 - \beta_1{}^0)}{\kappa_1}.$$

it follows that the configurations in question, both for $M > M_0$, and for $M \leq M_0$, will all obey the same mass-luminosity correlation. Thus the configurations we have held to resemble the B, O-stars, the giant red stars, and the main sequence of stars of nature all obey the same approximate mass-luminosity correlation. The configurations we have held to resemble the nuclei of planetary nebulæ and the white-dwarfs will depart from this correlation in the sense of possessing arbitrarily smaller luminosities for given mass" Milne, loc. cit., page 633.

A study of the physical properties, such as central temperature, etc., of the two-phase configurations with particular reference to white-dwarf stars has been made in the authors paper[5] already referred to.

As yet no systematic investigation of configurations with other-phase combinations have been made.

In the paper to follow, we shall consider non-relativistic degenerate and relativistic degenerate phase combinations.

*Note I.* A simple physical illustration of the three types of energy-generating processes discussed in the text:—

Consider a metallic bar of unit cross-section. Suppose it to be thermally insulated all round except at its two ends. Let one end be kept at $0^0$ and the other end be enclosed in a thermally insulated chamber B.
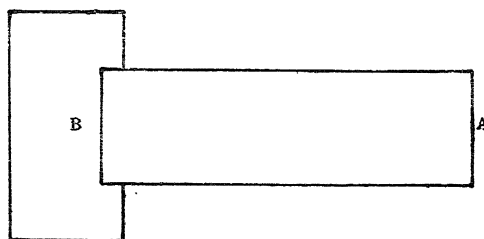


Fig. 3

Case (*a*). Let a unit mass of the energy-generating material be introduced in B (for example, a radioactive element). Then in steady-state, the heat flow H will be:        $H = \varepsilon$. (i),                $H = -\lambda \dfrac{dT}{dr}$ (ii)

and therefore $T_B$ the (temperature of the end B) is $\varepsilon l/\lambda$, *l* being the length of the bar.

Case (*b*). Suppose that $\varepsilon = aT^s$

(For example, the energy source may be a resistance coil connected to constant voltage supply. The resistance and hence the heat generated will be a function of the temperature of the coil).

In steady-state

$$H = aT^s \tag{$i$}$$

$$H = -\lambda \frac{dT}{dr} \tag{$ii$}$$

and hence

$$T_B = \left\{ \frac{\lambda}{a\,l\,(s-1)} \right\}^{\frac{1}{s-1}}$$

and

$$H = a \left\{ \frac{\lambda}{a\,l\,(s-1)} \right\}^{\frac{1}{s-1}}$$

Case (*c*). Introduce in B a reversibly reacting mixture in equilibrium $\left\{ A + \rightleftarrows AB + X \text{ calories} \right\}$. In this case we shall have no equation corresponding to (*i*) in the above two cases and hence H and $T_B$ cannot be determined from steady-state considerations alone.

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# ON THE ABSORPTION SPECTRA OF SOME SIMPLE SALTS OF THE TRANSITION ELEMENTS.

### (CONTRIBUTION TO THE THEORY OF THE CO-ORDINATE LINKAGE, V[1])

BY S. MUJTABA KARIM AND R. SAMUEL.

The question of the colour of Inorganic salts of the transition elements has occupied the attention of many workers since a long time. In the more recent times G. Joos[2] has observed that these salts in solution have the same colour as that of their crystals. In general he concluded that the colour is due to aqua complexes formed by the water of crystallisation. He believed that the colour could not be due to the free metal ion because, he thought, that the term differences which were not very well known then, for the resonance lines of these would be very great on account of the high degree of ionisation, and therefore the absorption due to the Cations should be in the ultra-violet but not in the visible. Later White[3] gave a classification of the terms of $Cr^{3+}$ ion. Saha[4] then observed that some of the maxima in the violet and the green solutions of $CrCl_3$ were really in excellent agreement with the two deepest term differences of the $Cr^{3+}$ ion as given by White. About the same time S. Kato[5] when taking preliminary absorption measurements came to the same conclusion. In the mean time H. Sauer[6] has shown that some complex Chromium compounds in the forms of alums at low temperatures (between -80°C and -180°C) show line absorption at about 6700$\lambda$ which he ascribes to the complex $[Cr (H_2O)_6]^{3+}$. The absorption shifts to longer wave lengths with increasing temperatures. Joos and Schnetzler[7] have also found line absorption in the red region of the spectrum in a great number of Chromium complex salts at low temperatures. Recently D. M. Bose[8]

and collaborators have come to the conclusion that the absorption bands of some of these ions in solutions are in fair agreement with the known term difference of the free metal ions.

The ealier measurements being in many cases not quite satisfactory, the following piece of work was undertaken with a view to investigate the problem in detail on a wider experimental basis.

The absorption coefficients of the following salts in solution were measured:—

$VCl_3$; $Na_2CrO_4$; $K_2Cr_2O_7$; $CrCl_3.6H_2O$; $MnCl_2$; $KMnO_4$; $FeCl_3.6H_2O$; $FeCl_2$; $CoCl_2.6H_2O$; $YCl_3$; $RuCl_3$; $RhCl_3.4H_2O$; $PdCl_2.2H_2O$; $OsCl_4$; $IrCl_4$; and $NiCl_2.6H_2O$.

The method of experimental procedure was the same as adopted by R. Samuel[9]. The solutions were prepared in the usual way in suitable solvents. It is thought desirable to add a few remarks about the behaviour and treatment of some of the salts.

$VCl_3$:—This substance was obtained by dissolving $VCl_4$ in water and leaving it for two days. Chlorine was given off and $VCl_4$ was turned into $VCl_3$.

It has a large hydrolysis and the solution contains also $V_2O_3$.

$CrCl_3.6H_2O$:—This substance gives a green and a violet solution. We have especially treated the green one. When one mole of the substance is dissolved in 100 litres of water, the amount of hydrolysis in the solution is to the extent of 9.4%. The green solution shows an equilibrium between $[CrCl(5H_2O)]$ $Cl_2$ and $[CrCl_2(4H_2O)]$ Cl ions, while the violet solution, obtained after keeping the green solution for some time, shows free $Cr^{3+}$ and $3Cl^-$ ions.

$FeCl_3.6H_2O$:—It is a yellow very delequescent solid soluble in water. When 1 mole of the substance is dissolved in 6.4 litres the amount of hydrolysis is 2%, but it increases with dilution to 37% for one mole in 33.3 litres. The hydrolysis also increases with time, which seems to indicate the presence of Fe $(OH)_3$ ions in collidal form in water and therefore the different measurement can not be expected to show good agreement.

$OsCl_4$:—is strongly hydrolysed in solutions and contains a high percentage of $OsCl_3$. Therefore the results obtained are uncertain. $IrCl_4$ too is strongly hydrolysed in solutions.

$CoCl_2.6H_2O$:—The amount of hydrolysis is ·11% for one mole in 16 litres of water.

$NiCl_2.6H_2O$:—When 1 mole of the substance is dissolved in 35.2 litres of water the hydrolysis is· 3% .

⚬ $YCl_3$:—is soluble in water on the addition of a little HCl. When 1 mole of the substance is dissolved in 10 litres of water the amount of hydrolysis is ·01% at 16°C.

There is no hydrolysis in the solutions of $Na_2CrO_4$ and $K_2Cr_2O_7$, but the absorption spectra depends on the acidity of the solutions, as shown by Jander[10].

In the case of $MnCl_2$; $RuCl_3$; $RhCl_3.4H_2O$; $PdCl_2.2H_2O$; the amount of hydrolysis is very small. Similar is the case of $KMnO_4$ but it is sensitive to Organic impurities.

## DISCUSSION

The results obtained are presented in the accompanying diagrams and tables and we shall proceed to discuss them. We shall treat in detail the results for the Chromium Chloride. The different solutions of this salt show maxima at 669, 632, 605, 527, 440 (470 till 410) and 280 m$\mu$. In order to classify these we make use of the two older and more qualitative measurements of Bjerrum[11] and Byke and Jaffe[12]. These authors prepared different forms of Chromium Chloride with different amounts of water of crystallisation. This enables us to say by comparison of results that the maxima at 669m$\mu$ may be due to the ion $(Cr + 6H_2O)^{3+}$. while those at 632m$\mu$ and 605m$\mu$ are due to $(CrCl_2 + 4H_2O)^+$ or $(CrCl + 5H_2O)^{2+}$. The maximum at 527 m$\mu$ clearly belongs to the violet solution only, being stronger—in the m/100 and missing in the m/10 solution and can therefore be ascribed to $(Cr + 6H_2O)^{3+}$ or $Cr^{3+}$. There remain only the two maxima at 440 m$\mu$ and 280 m$\mu$ for which we are not able to give a definite classification, but which we believe belong either to $(CrCl_2 + 4H_2O)^+$ or $(CrCl + 5H_2O)^{2+}$.

If we compare these maxima with the term differences of the ion $Cr^{3+}$, it is interesting to find that just those maxima which on other and mainly chemical grounds we have attributed to the ion $(Cr + 6H_2O)^{3+}$, agree with the lower term differences of the $Cr^{3+}$ion. These term differences are those to which Saha has already drawn attention viz $^4F - {}^2G = 15014$ cms$^{-1}$. and $^4F - {}^2H = 21027$

cms⁻¹ (for the lowest component). These correspond to the maxima at 669mμ (about 15,000 cms⁻¹) and 527mμ (about 19000 cms⁻¹) the coincidance being quite satisfactory if it is remembered that the absorption maxima in solutions are always rather diffuse.

This coincidence was quite expected; but what is more surprising is the following relation. The maxima ascribed to $(CrCl_2 + 4H_2O)^+$ or $(CrCl + 5H_2O)^{2+}$ correspond to the deepest term differences of the spectra of the free $Cr^+$ and $Cr^{2+}$ ions respectively. The ground term of $Cr^+$ is $^6S$ and the next term $^6D$ is only about 12500 cms⁻¹ higher, so that the band corresponding to this term difference lies in the near infra-red and cannot be observed in our experiments. The next term difference, however, $^6S - ^2P$ is 16896 cms⁻¹, which agrees very well with the maxima at 632 or 605mμ (about 16000 to 16600 cms⁻¹). Similarly for $Cr^{2+}$ the first term differences are $^3F - ^5D$, $^3G - ^5D$, and $^3F - ^3F$ with about 19000, 21000, and 38000 cms⁻¹ respectively. Whereas the emission spectrum of $Cr^3$ accounts for two of the six absorption maxima only, the others are all accounted for by the term differences of $Cr^{2+}$ and $Cr^+$. (see Table 1).

This remarkable coincidence if established, leads us to certain important conclusions. So an attempt at similar correlation was made for the absorption maxima of other salts. In this case, however, we meet with a certain handicap. Thus in the case of $MnCl_2$, nearly nothing is known about the spectrum of the free $Mn^{2+}$ ion. The absorption maximum at 262 mμ (about 38000 cms⁻¹) coincides very well with the second deepest term difference $^7S - ^7P = 38366$ cms⁻¹ of $Mn^+$, but we are not able to show definitely, for want of data, that it does not belong to some deep term difference of $Mn^{2+}$. A solution of $KMnO_4$ was treated with $H_2SO_4$ and $H_2O_2$ to study the absorption spectrum of $MnSO_4$. This curve shows that the maximum at 262 mμ of $MnCl_2$ has disappeared in the case of $MnSO_4$, where there is no possibility any longer for compounds like $[MnCl + 5H_2O]^+$.

In the same way the absorption maxima in the solution of $FeCl_3 \cdot 6H_2O$, corresponds quite well with the $Fe^+$ spectrum (See Table IV for deatils); we cannot check the correspondence with $Fe^{3+}$ because the latter spectrum is not analysed. Similar remarks hold good in the case of $CoCl_3 \cdot 6H_2O$, where only $Co^+$ spectrum is known; the first term difference which lies in the visible can be found again in the absorption spectrum of the $CoCl_2 \cdot 6H_2O$, but there is no possibility now of comparing the result with the $Co^{2+}$ spectrum. The case of $PdCl_2 \cdot 2H_2O$ is similar, (See Table VII).

Still more interesting is the absorption spectrum of $NiCl_2 6H_2O$. If we include the measurements of Dreisch[13] in the Infra-red with ours we see that the first four term differences of $Ni^+$ are in nearly perfect agreement with the four absorption maxima of $NiCl_2$. But here also the absorption maxima cannot be compared with the spectrum of $Ni^{2+}$ which is not known. (Table VI)

The case of $YCl_3$ is slightly different. This shows an absorption maximum at 265 m$\mu$ (about 38000cms$^{-1}$). The ground term of $Y^{2+}$ is $^2D$; the next term is $^2S$ being 7966 cms$^{-1}$ higher up; the term difference gives a line in the Infra-red; the next higher term is $^2P$ which is 41404 cms$^{-1}$ higher than the ground term. We see, therefore, that the absorption maximum at 265 m$\mu$ can be indentified satisfactorily with this term difference. The spectrum of $Y^{3+}$ is not yet analysed, but it can be readily seen that this spectrum will be analogous to that of $Rb^{2+}$ or $Na^{2+}$. The excitation of $Y^{3+}$ i.e. the fourth electron of Y means already the excitation of an electron in the next closed shell. So the spectrum of $Y^{2+}$ will have none of its deeper term differences in the visible or the near ultra-violet. In a certain sense, therefore, the correlation between the spectrum of $Y^{2+}$ and the absorption maximum $YCl_3$ may be said to have been directly established, the more so because the small amount of hydrolysis shows that the spectrum belongs really to the $YCl_3$.

The main results may be summed up as follows:—

(A) The coincidence which was first pointed out by Saha and later on by Bose between the absorption maxima and the term differences of the ions supposed to be in the solutions in the case of $CrCl_3.6H_2O$ and $VCl_3$ is verified by these experiments.*

(B) In the case of $CrCl_3.6H_2O$ where the specturm of $Cr^+$, $Cr^{2+}$, and $Cr^{3+}$ are all known, we find that there are other maxima of absorption which coincide with the deepest term differences of $Cr^{2+}$ and $Cr^+$, in addition to these which correspond to those of $Cr^{3+}$.

(C) Such coincidences between the absorption maxima and the deeper term differences of the ions in less ionised states than are originally supposed to be in the solution is also found in the case of $MnCl_2$; $FeCl_3.6H_2O$; $CoCl_2.6H_2O$; $NiCl_2$.

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* We are not able to agree with the conclusions of Bose about the $Ti^{3+}$ ion, because the absorption maximum of $TiCl_3$ although it agrees with certain term differences of the $Ti^+$ neither of these two is the ground term. The difference between the deepest of the levels and the ground level is 24 volts and it is difficult to believe that the ion can come directly in this excited state.

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$6H_2O$ ; $YCl_3$ ; and $PdCl_2.2H_2O$. In these six cases, however, the spectrum of the ion supposed to be in the solution are not analysed and so it is not possible to check the results. But the number of cases in which we find the coincidences mentioned above is sufficiently large to believe that the coincidences are not fortuitous.

(D). In two of these six cases, viz, $MnCl_2$ and $YCl_3$ we have been able to offer indirect evidence, mostly chemical in the first salt and spectral, by estimation of the deepest term difference, in the second case to show that the coincidence mentioned in (C) is rather real.

With all due reservations, therefore, we feel we are justified in discussing in detail some of the consequences of these results.

Making use of the qualitative measurements of some of the chemists it has been shown that in the case of the solutions of Chromium salts studied, the ion $(Cr + 6H_2O)^{3+}$ exhibits absorption maxima which correspond to the spectrum of $Cr^{3+}$ ion. Similarly the ions $(CrCl + 5H_2O)^{2+}$ and $(CrCl_2 + 4H_2O)^+$ show absorption maxima which belong to the spectra of $Cr^{2+}$ and $Cr^+$. This in itself is an interesting fact. In former communications of this series of contribution it was observed that the absorption maxima of e. g. the Hexacyanides of the same transition elements shared no such correspondence with the spectra of the free metal ions. The present fact may be taken, therefore, as an argument in favour of ascribing different kinds of linkage to the genuine complexes like the Cyanides mentioned and those loose complexes formed by the metal in association with the solvent. We shall assume, therefore, that the water in association does not affect the absorption of the ion. So in general we may say that the absorption maxima of the ion e. g. $(MeCl + 5H_2O)^{2+}$ is really the spectrum of a compound $(MeCl)^{2+}$. We have now to explain how it happens that the absorption maxima of such a compound $(MeCl)^{2+}$ correspond to the spectrum of the free $Me^{2+}$ ion. This we shall do by taking an example of $(MeCl)^+$. We make a plausible assumption that molecules of the type $(MeCl)^+$ etc. are very unstable. This gives us an explanation which is clear from the following potential energy diagram, connecting the inter-nuclear distances $r$ with the potential energy $U$ of the molecule in the excited and the unexcited states. The difference between this curve and a similar curve for a normal stable molecule is that in this case $D$ and $D'$ are very much smaller than either the atomic term differences of the dissociation products or the molecular term differences of the molecule itself,
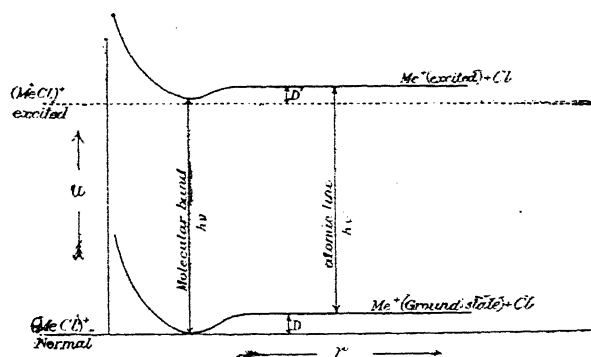
D and D' being small quantities their difference D – D' will be still smaller. The smaller this quantity becomes the more will $h\nu - h\nu^1$ tend to be equal. Thus it will be clear that the agreement observed, if definitely established, finds an easy explanation.

The salts containing oxygen, viz. $KMnO_4$, $K_2Cr_2O_7$ and $Na_2CrO_4$ do not show any relation to the term differences of the metal ions concerned. The absorption curve of $KMnO_4$ was also measured by A. Hagenbach and R. Percy in solution and by K. Schnetzler in solid state at low temperatures in the visible region of the spectrum, and a comparison of the three results is shown in the following table.*

| Hagenbach & Percy | 6370 | 5707 | 5470 | 5252 | 5054 | 4865 | 4701 | 4540 | 4395 | ... |
|---|---|---|---|---|---|---|---|---|---|---|
| Schnetzler ... | ... | ... | 5537 | 5312 | 5102 | 4911 | 4735 | 4567 | 4414 | ... |
| Karim & Samuel... | 6250 | 5700 | 5410 | 5210 | 5040 | 4780 | ... | ... | ... | 3140 |

Here we see that our results coincide fairly well with the measurements of Hagenbach and Percy except that some of the maxima cannot be traced or that they are so much diffused in our curve that we cannot trace them with any great accuracy.

K. Schnetzler has shown that at low temperatures these maxima become real bands, and he treats them as vibrational bands of electronic band system.

* The figures of the above table have been taken from the paper of Schnetzler. Zs. f. Phy. Chem. B. 14, 247, 1931.
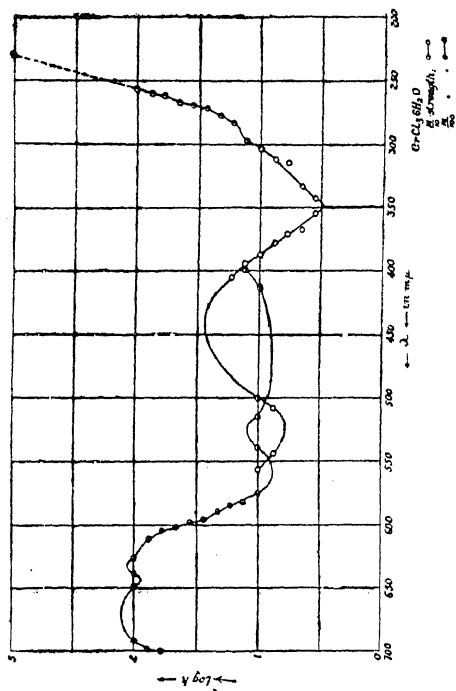
Fig. 1. CrCl₃
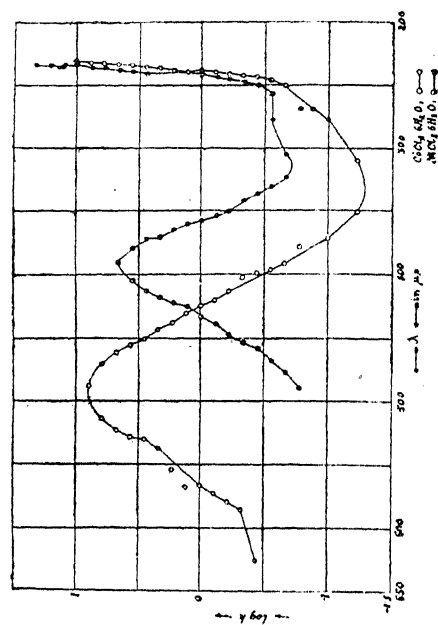
Fig. 3. CoCl₂ and NiCl₂
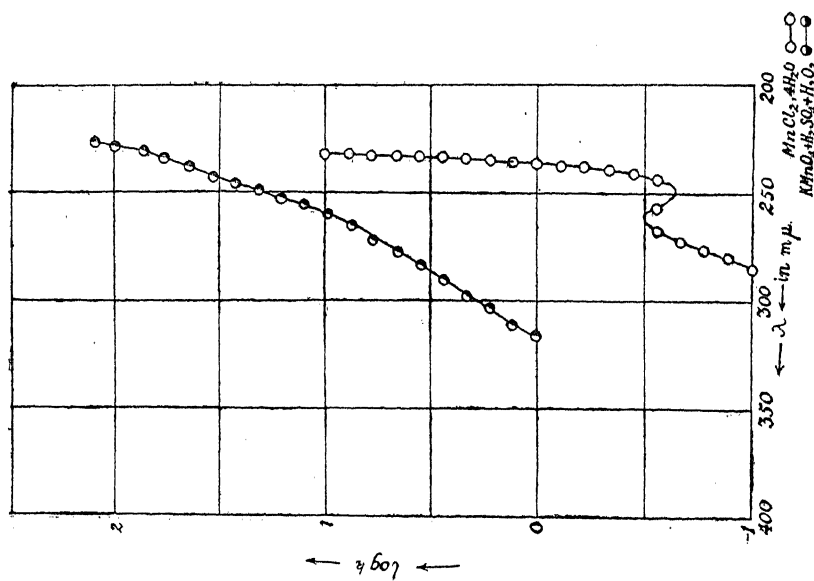
Fig. 2. MnCl₂

It is to be noted that all these bands belong to one main maximum in the solution. Apparently in the solution the distribution of the molecules over these vibrational states are quite different from those in the crystal at low temperatures.

The curves of $Na_2CrO_4$ and $K_2Cr_2O_7$ are very similar, so that we may assume that the main absorbing ion is the same in both the cases, probably $HCrO_4$. The difference in the height of the maxima of the two curves can also be explained by the fact that the one contains double the number of Cr atoms than the other and has therefore double the probability of forming $HCrO_4$ ions. These curves and especially the many bands of the $KMnO_4$, show no similarity with the absorption bands either of the simple salts treated above or the absorption bands of the complex salts treated in other papers of this series.

TABLE 1.    ($CrCl_3$)

| Max of absorption of $CrCl_3$ in Water | | Emission Spectra of Cr. | | | | | |
|---|---|---|---|---|---|---|---|
| | | Cr IV Ground level $^5F$ | | Cr III Ground level $^5D$ | | Cr II Ground level $^6S$ | |
| $\lambda m\mu$ | $\nu\ cm^{-1}$ approx | $\nu\ cm^{-1}$ | Combin | $\nu\ cm^{-1}$ approx | Comb. | $\nu\ cm^{-1}$ | Comb. |
| | | | | | | 12500 | $^6D-^6S$. |
| 669 | 15000 | 15014 | $^2G-^5F$ | | | | |
| 632 | 16000 | | | | | 16896 | $^2P-^6S$. |
| 605 | 16500 | | | | | | |
| | | | | 19000 | $^3F-^5D$ | 19529 | $^4D-^6S$ |
| 527 | 19000 | 21027 | $^2H-^5F$ | | | 20514 | $^4G-^6S$ |
| | | | | | | 21824 | $^2D-^6S$ |
| 440 | 22700 | | | 21000 | $^3G-^5D$ | | |
| | | | | | | Many more terms. e.g. of combination $d^5$. | |
| 280 | 35500 | | | | | 32847 | $^4F-^6S$. |

TABLE II. ($MnCl_2$).

| MAX OF ABSORPTION OF $MnCl_2$ IN WATER | | EMISSION SPECTRA OF Mn | | | | |
|---|---|---|---|---|---|---|
| | | Mn IV | Mn III | | Mn II Ground level $^7S$ | |
| $\lambda\ m\mu.$ | $\nu\ cm^{-1}$ approx | | | | $\nu\ cm^{-1}$ | |
| 262 | 38000 | ? | ? | | 14324 38366 43370 | $^5D - {^7S}$ $^7P - {^7S}$ $^5P - {^7S}$ |

TABLE III. ($YCl_3$).

| MAX. OF ABSORPTION OF $YCl_3$ IN WATER. | | EMISSION SPECTRA OF Y | | Y III Ground level $^2D$ | |
|---|---|---|---|---|---|
| | | Y IV | | | |
| $\lambda\ m\mu$ | $\nu\ cm^{-1}$ approx | | | $\nu\ cm^{-1}$ | |
| 265 | 38000 | ? | | 7466 44404 | $^2S - {^2D}$ $^2P - {^2D}$ |

TABLE IV. ($FeCl_3$)

| MAX. OF ABSORPTION OF $FeCl_3$ IN WATER | | EMISSION SPECTRA OF Fe | | | FeII Ground level $^6D$ | |
|---|---|---|---|---|---|---|
| | | Fe IV | Fe III | | | |
| $\lambda\ m\mu$ | $\nu\ cm^{-1}$ approx | | | | $cm^{-1}$ | |
| 1020 790 340 | 9800 13000 29000 | ? | ? | | 8846 13474 20830 22637 25428 31364 | $^4D - {^6D}$ $^4P - {^6D}$ $^4P - {^6D}$ $^4F - {^6D}$ $^4G - {^6D}$ $^4D - {^6D}$ |

Fig. 4. $VCl_3$

## TABLE V. (CoCl$_2$).

| MAX. OF ABSORPTION OF CoCl$_2$ IN WATER | | EMISSION SPECTRA OF Co | | | | | |
|---|---|---|---|---|---|---|---|
| | | Co IV | | Co III | | Co II GROUND LEVEL $^3$F | |
| $\lambda m\mu$ | $\nu\ cm^{-1}$ approx | | | | | $\nu\ cm^{-1}$ | |
| 1250 | | | | | | 5000 | $^5$P – $^3$F |
| 770 | 12900 | | | | | 10708 | $^3$F – $^3$F |
| 565 | 17700 | | ? | | ? | 17771 | $^5$P – $^3$F |
| 515 | 19400 | | | | | | |
| 488 | 20500 | | | | | | |
| 405 | 24700 | | | | | | |
| 365 | 27400 | | | | | | |
| 250? | 40000 | | | | | 45197 | $^5$F – $^3$F |

## TABLE VI. (NiCl$_2$).

| Max. of absorption of NiCl$_2$ in water. | | EMISSION SPECTRA OF Ni | | | | | |
|---|---|---|---|---|---|---|---|
| | | Ni IV | | Ni III | | Ni II Ground level $^6$D. | |
| $\lambda\ m\mu$ | $\nu\ cm^{-1}$ approx | | | | | $\nu\ cm^{-1}$ | |
| 1200 | | | | | | 8 - 10000 | $^4$F – $^2$D. |
| 720 | 13900 | | | | | 13549- | $^2$F – $^2$D. |
| 445 | 22500 | | ? | | ? | 14994 | |
| 390 | 25600 | | | | | 23106 | $^2$D – $^2$D. |
| 270 | 37000 | | | | | | |
| 238 | 42000 | | | | | | |

## TABLE VII. (PdCl$_2$).

| Max. of absorption of PdCl$_2$ in water. | | EMISSION SPECTRA OF Pd. | | | | | |
|---|---|---|---|---|---|---|---|
| | | Pd IV | | Pd III | | Pd II Ground level $^2$D | |
| $\lambda\ m\mu$ | $\nu\ cm^{-1}$ approx | | | | | $\nu\ cm^{-1}$ | |
| 456 | 21900 | | | | | 25081 | $^1$F – $^2$D |
| 350 | 28600 | | ? | | ? | 32277 | $^2$F – $^2$D |
| 278 | 35900 | | | | | 36281 | $^4$P – $^2$D |
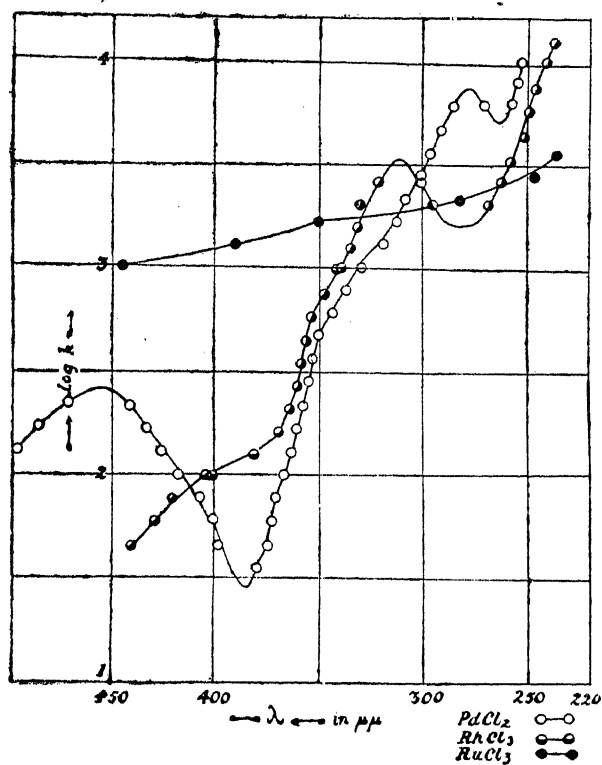
FIG. 6.    PdCl₂, RhCl₃, RuCl₃

PdCl₂    ○—○
RhCl₃    ◐—◑
RuCl₃    ●—●
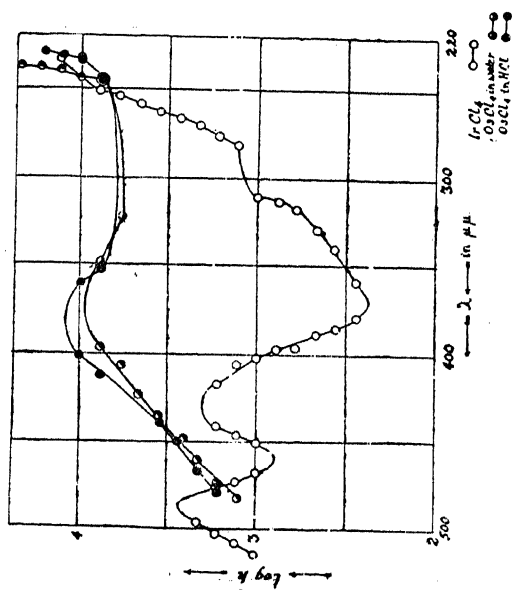
FIG. 8.    KMnO₄
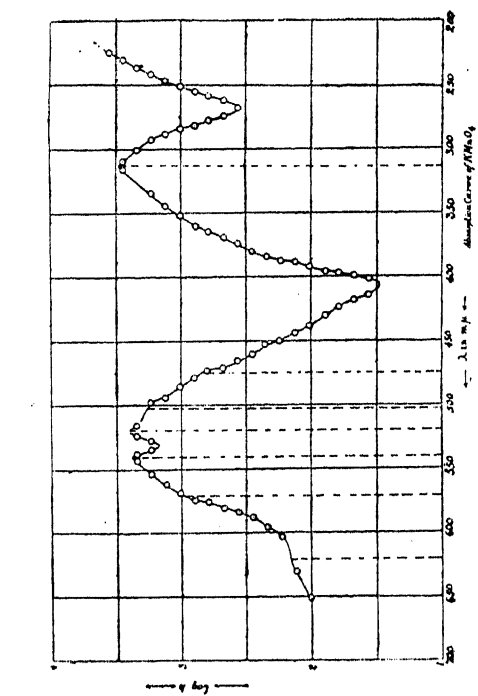
FIG. 7.    IrCl₄, OsCl₄
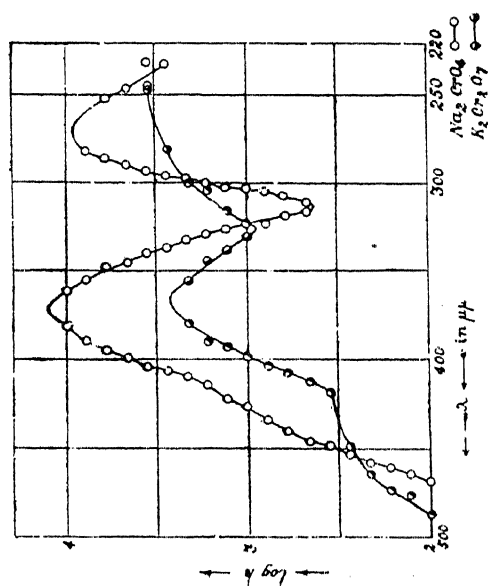
FIG. 9.    Na₂CrO₄

TABLE VIII. (VCl₃).

| Max. of absorption of VCl₃ in water. | | EMISSION SPECTRA OF V. | | | |
| --- | --- | --- | --- | --- | --- |
| | | V IV Ground level $^3$F | | V III | |
| $\lambda\ m\mu$ | $\nu\ cm^{-1}$ approx. | $\nu\ cm^{-1}$ | | | |
| 470 | 21300 | 19807 | $^1$G – $^3$F | | |
| 410 | 24400 | 20091 | $^1$S – $^3$F | | |

Other terms lie in the extreme red and in Infra red.

TABLE IX.

The Emission spectra of RhCl₃; IrCl₄; and OsCl₄ being not yet analysed, only the Maxima of absorption are given below :—

| Max. of absorption of RhCl₃ in water. | | Max. of absorption of IrCl₄ in water. | | Max. of absorption of OsCl₄ in water. | |
| --- | --- | --- | --- | --- | --- |
| $\lambda\ m\mu$ | $\nu\ cm^{-1}$ approx. | $\lambda\ m\mu$ | $\nu\ cm^{-1}$ approx. | $\lambda\ m\mu$ | $\nu\ cm^{-1}$ approx. |
| 370 | 27000 | 185 | 20600 | | |
| 350 | 28600 | 429 | 23300 | | |
| | | | | 373 | 26700 |
| | | 408 | 24500 | | |
| 311 | 32100 | 280 | 35700 | | |

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NEW BLOOD FLUKES OF THE FAMILY SPIRORCHIDAE STUN-
KARD FROM INDIAN FRESH-WATER TORTOISES WITH
DISCUSSION ON THE SYNONYMY OF CERTAIN GENERA
AND THE RELATIONSHIPS OF THE FAMILIES OF
BLOOD FLUKES.—PART II.

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## INTRODUCTION

While we described two new species of the new genus *Coeuritrema* in a paper published in Vol. 2, No. 4 of this journal, we discussed the systematic position of that genus and relationships of the family Spirorchidae with the Schistosomatidae. It was shown in the course of discussion that the subfamily Hapalotreminae represents the primitive blood flukes, from which are evolved along one line the Schistosomidae and along the other close to the subfamily Spirorchinae, the blood flukes of fishes belonging to the families Aporocotylidae and Sanguinicolidae. In this paper are described four new species of blood flukes assigned to a new genus *Plasmiorchis*, which as will be seen from the description and subsequent discussion is closely related to the American genus *Spirorchis*. The resemblance between these two genera is so close that at first sight it appeared desirable to create two subgenera under the genus *Spirorchis*, one for the American species and the other for Indian forms described in this paper. But the closer examination revealed that the presence of a ventral sucker and forwardly directed loops of the intestinal caeca, one on each side of the oesophagus, are such constant features of the Indian species as to necessitate their inclusion in a separate genus, which we call *Plasmiorchis* on account of their habitat in the blood plasma of their hosts.

Odhner in 1911 while discussing the relationships of *Aporocotyle* with *Sanguinicola* pointed out that the H-shaped gut of the latter is derived by a great reduction in length of that of the former. He also mentioned that the

condition of the alimentary system in *Deontacylix* shows an intermediate condition between that of *Sanguinicola* and *Aporocotyle*. It seems obvious that we have got a descending series in the evolution of the alimentary system of the four genera of suckerless trematodes hitherto known, *Aporocotyle—Psettarium—Deontacylix—Sanguinicola,* all blood flukes of fishes. The presence of forwardly directed loops at the origin of caeca in *Plasmiorchis* gives us a clue to the origin of the anterior blindly ending lobes of the gut of the above-mentioned genera. It is, therefore, near the subfamily Spirorchinae particularly its genus *Plasmiorchis,* where we have to look for the ancestors of *Aporocotyle* and its descending series of genera *Psettarium Deontacylix,* and *Sanguinicola.*

In view of the recent addition of a number of genera, the classification of the family Spirorchidae as given by Stunkard in 1923 has been revised. The genera *Henotosoma* Stunkard and *Haematotrema* Stunkard are held identical with the genus *Spirorchis* and are merged into it. The genus *Tremarhynchus* Thapar is held synonymous with *Coeuritrema,* the latter name being accepted on the basis of priority. *Tremarhynchus indicus* is consequently assigned as the third species to that genus under the name of *Coeuritrema indicus* (Thapar, 1933).

### Plasmiorchis orientalis nov. gen., nov. spec.

#### (Figs. 1, 4, 8, 9)

Three mature specimens were obtained in August 1931 and two in September 1932 from the ventricle of the heart of two water tortoises of the species *Kachuga dhongoka* at Allahabad. The blood flukes came out as soon as the ventricle was opened in salt solution and appeared inactive indicating no movements. The body is elongated fusiform or spindle-shaped, slightly tapering towards ends like that of the genus *Spirorchis ;* it is thin specially at edges, flattened and transparent with the anterior end a little more pointed than the posterior. The size is very small, measuring 2·26*—3 in length and 0·4-0·6 in greatest breadth, which lies about the middle of body length. The breadth measures 0·38 – 0·5 in the region of the intestinal bifurcation, 0·27-0·56 in that of the ventral sucker and 0·34—0·56 in that of the ovary, varying within the narrow limits of 0·33—0·4 or 0·5—0·6 between the intestinal bifurcation and the ovary. The body wall is covered with very thin cuticle and is devoid of papillae, but it is covered with fine needle-like spines, which hardly project outside it. The musculature of the body is poorly developed.

The oral sucker is oval, longer than broad and protrusible, measuring 0·102-0·108 in length and 0·066 in maximum breadth. It protrudes ordinarily

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* All measurements are given in millimeters.

only a little in front of the anterior end; in none of my specimens it is half or entirely protruded. The ventral sucker is well developed, protrusible and rounded, measuring 0·128 — 0·144 in diameter ; in one specimen of 2·5 length it measures 0·081 in length and 0·087 in breadth, while the oral sucker in this specimen measures 0·102 in length and 0·066 in breadth. The ventral sucker lies 0·192 — 0·272 behind the intestinal bifurcation and 0·73 — 0·75 behind the anterior end, *i.e.*, at about one third body length from the anterior end; in one specimen, however, it lies between one third and one fourth body length from the latter. The pharynx is absent. The oesophagus, 0·4 in length and 0·066 — 0·069 in greatest breadth is long and sinuous with two to four bends, extending up to 0·48 length of the body from the anterior end, *i.e*, about anterior one sixth body length. It is surrounded by deeply staining salivary gland cells, which are found in large numbers around its posterior part. Its inner wall appears plicated on account of the continuous discharge of salivary secretion through it into the lumen; the plications are more pronounced in the terminal part immediately in front of the intestinal bifurcation. At the point where it bifurcates into the caeca, it gives off behind the origin of the latter a small median pocket, the oesophageal vesicle. The caeca do not pass laterally as soon as they arise as in the genus *Spirorchis,* but they turn abruptly forwards running one on each side of the oesophagus for nearly one third or one half of its length and then bend downwards forming characteristic U-shaped loops as they continue their course to the hinder end. The presence of these forwardly directed loops is a characteristic feature of all the species belonging to the new genus. The caeca then run almost straight but for a short outward bend displayed by the left caecum in the region of the genital pore, the genital loop and terminate near the hinder end, where they converge a little towards each other lying parallel for a short distance. They are simple without diverticula, having more or less uniform breadth of 0·075, and lie half way between the body wall and median line except near their ends.

The excretory pore is slightly dorsal at the posterior end. The excretory bladder has a very small stem bifurcating into two wider branches, which could be traced up to the blind ends of the caeca. The glandular vesicle, which Stunkard considers as the lymph vesicle in the genus *Spirorchis* is not seen in sexually mature specimens. In immature specimens, however, it is present at the hinder end in the median line behind the vitelline reservoir, having a curved S-shaped appearance.

Main parts of the nervous system are visible in entire mounts. The oesophageal commissure is fairly prominent. It lies 0·096 distance behind the oral sucker, *i.e*, at about one fourth distance from it and is slightly swollen on each side to form an indistinct ganglionic mass from which the main lateral nerve arises. The lateral nerves run posteriorly close outside the caeca on the ventral surface of the body as in *Spirorchis.*

The reproductive organs resemble essentially those of the genus *Spiror-chis.* The testes, 5-7 in number, lie in a linear series in the median plane usually in close contact with one another, almost filling the intercaecal region between the ventral sucker and ovary. They are irregularly lobed, elliptical or ovoid in shape, flattened and broader than long, measuring 0'14—0'24 in length and 0'208—0'24 in breadth. The anterior and posterior testes are larger than the middle ones. The anterior testis lies a little behind the ventral sucker, 0'03—0'12 distance behind it and 0'033—0'53 behind the intestinal bifurcation. The testicular area occupies a little less than half the length of the body. There is no vas deferens The vesicula seminalis, filled with sperms, is pear-shaped with the widest anterior end pressed against the left part of the posterior margin of the hindmost testis, situated usually to the left side and slightly overlapped by the inner margin of the ovary, filling almost the entire space between it and the left caecum. In a few specimens, however, it lies almost entirely ventral to the ovary, commencing a little in front of the latter, from the posterior margin of the hindmost testis. It extends backwards as far as the posterior limit of the ovary or a little behind it to the left side near the left caecum, where it enters the cirrus sac, measuring 0'27 in length and 0'075—0'105 in maximum breadth in its widest anterior end. The cirrus sac is extremely small with poorly developed musculature, some-what oval or pear-shaped with the narrow end opening at the genital pore, and situated beneath or close inside the left caecum, measuring 0'09-0'13 in length and 0'03—0'054 in maximum breadth at its end near the vesicula seminalis. It contains inside a small vesicula seminalis interna of rounded or oval outline and of 0'045 diameter, followed by a sharply constricted off ductus ejaculatorius. The latter is pear-shaped, measuring 0'09 in length and 0'03 in greatest breadth near its proximal end. The genital opening lies 0'28—0'29 distance in front of the hinder end, and a little, *i.e.,* 0'128 distance behind the ovary, to the left side beneath the left caecum, where the latter is slightly bent outwards to form the characteristic genital loop. The cirrus sac opens anteriorly to the metraterm at the genital pore. The prostate gland cells are absent.

The ovary is much lobed, and lies median or slightly to the right side with its outer wall close inside the right caecum, immediately behind the hindmost testis at a distance of 0'4—0'6 from the posterior end, *i.e.,* at about one fifth body length from it. It overlaps partly or entirely the basal part of the vesicula seminalis, measuring 0'24 by 0'176, 0'176 by 0'112 and 0'9 by 0'9 in size in the three specimens examined for the purpose. The oviduct ori-ginates from the middle of its posterior margin, and after running a short distance dorsally backwards joins the receptaculum seminis which is filled with sperms. The receptaculum seminis is of an oval or spherical shape, and lies to the right side close behind the ovary, measuring 0'045 – 0'06 in

length and 0'05—0'075 in maximum breadth. We follow Ejsmont in calling this vesicle, the receptaculum seminis instead of receptaculum seminis uterinum as Ward and Stunkard have called it. The oviduct leaves the latter at the hinder end, and receives the small Laurer's canal ; it then continues its course slightly to the left side, a little behind the level of the genital opening to receive the yolk reservoir, where it sharply turns forwards to open into the broad oval ootype or uterus, which contains a single large ovum. The uterus lies transversely, closely in front of the union of the transverse vitelline ducts, behind the receptaculum seminis, and enters terminally into a small metraterm with thin muscular walls. The latter opens to the exterior at the genital opening. The ovum is large, non-operculated and oval without filaments or spines, measuring 0'102—0'12 in length and 0'042—0'057 in maximum breadth.

The vitellaria are voluminous, and occupy lateral areas surrounding the caeca, extending from the middle of the oesophagus; *i.e.*, from the forward limits of the anterior loops of the caeca to almost the posterior end of the body. The follicles of small size lie mainly outside the caeca forming a continuous linear mass, the extracaecal areas, but they enter also the intracaecal region both dorsally and ventrally to form intracaecal areas. At the posterior end they generally meet in the intracaecal region between the blind ends of the caeca. The transverse vitelline ducts arise slantingly at about the level of the genital opening, the right a little in front of the left one, and unite closely behind the uterus near the ventral wall to form the backwardly directed vitelline reservoir, the narrow anterior end of which bends forwards on the dorsal side to open into the oviduct, near its junction with the uterus.

Four immature specimens were obtained from the ventricle of the heart of two *Kachuga dhongoka* (2 from each) dissected in November 1931. The body measures 1'5—1'9 in length and 0'37 -0'54 in maximum breadth, which lies in the region between the ventral sucker and the ovary The shape is elongated and fusiform with bluntly pointed ends. The oral sucker is oval and partly protrusible, measuring 0'09 by 0'05, and 0'1 by 0'06 in size in the two specimens examined for the purpose. The ventral sucker, 0'08—0'09 in diameter lies at about one third body length from the anterior end and 0'16—0'17 behind the intestinal bifurcation. The oesophagus, oesophageal vesicle and intestinal caeca with their characteristic loops are similar to those in mature specimens. The testes, 5—7 in number, are fairly large in size, containing mature sperms. The anterior testis, which is the smallest lies 0'096—0'135 behind the ventral sucker. The vesicula seminalis and ovary though small are developed in only one of the four specimens. The cirrus sac is indistinguishable. The vitellaria are entirely absent. The receptaculum seminis, present in only one specimen which possesses a very small slightly lobed ovary, is filled with sperms. From the study of immature specimens it is clear that the male reproductive organs are developed first and that the sperms for fertilisation are received in the

receptaculum seminis before the ovary is fully developed and functional. The vitellaria are developed last

Host—*Kachuga dhongoka.*

Habitat—Ventricle of heart.

Locality—Allahabad, India.

## Plasmiorchis pellucidus sp. n.

(Figs. 2, 5, 10)

Two mature and one immature specimens of this species were obtained from the ventricle of the heart of *Kachuga dhongoka* in November 1931. The body is very thin and transparent, measuring 3-3·26 in length and 0·64-0·68 in greatest breadth, which lies in the region from the ventral sucker to the ovary. The shape is fusiform with bluntly pointed ends as in the genus *Spirorchis.*

The oral sucker is oval, longer than broad, and protrusible, measuring 0·126 – 0·132 in length and 0·087 – 0·09 in greatest breadth. The ventral sucker is absent in mature specimens, but its position is indicated by a definite clear region devoid of musculature or body parenchyma. This region where the ventral sucker was present and has obviously dropped off leaving a clear empty space in the body, we prefer to call the ventral sucker area. In immature specimen, however, the ventral sucker is present. This condition shows clearly how the ventral sucker has been secondarily lost in the genus *Spirorchis.* The ventral sucker area lies at about the end of the anterior one third body length, and measures 0·24—0·32 in diameter. The pharynx is absent. The oesophagus is long and sinuous with four bends, measuring 0·64 in length. It is more or less of uniform breadth except anteriorly where it is slightly narrower. It is surrounded by salivary gland cells, which are more numerous and densely crowded around its posterior end, before it passes into the vesicle; its inner wall appears plicated on account of the salivary secretion, which passes through it into the lumen. The oesophageal vesicle is well developed, measuring 0·096 in length and 0·08 in breadth. The intestinal caeca arise at the junction of the vesicle with the oesophagus and soon turn abruptly forwards running parallel to the latter for about posterior half of its length till they bend downwards forming the characteristic loops on their way backwards, ending almost at the hinder end of the body. The caeca are simple without diverticula, much narrower than the oesophagus, and run almost straight till the genital pore where the left caecum is slightly bent outwards to form the inconspicuous genital loop, which is less marked than that in the previous species. They lie almost half way between the body wall and the median line, converging slightly inwards towards each other behind the genital opening. The excretory pore is slightly dorsal. The glandular vesicle

is not visible in mature specimens. The nervous system is similar to that of the previous species

The testes, 8—9 in number, lie in a linear series in the median line, close behind and in contact with one another, separated on either side by a considerable distance from the corresponding intestinal caecum. They are of varying shapes, but usually ovoid with entire margins, and broader than long, measuring 0˙09—0˙165 in length and 0˙105—0˙175 in maximum breadth; the third and fourth testes are usually the smallest. The first testis lies a little behind the ventral sucker area, 0˙08 distance behind it; the testicular area occupies a little less than half the length of the body. The vas deferens is absent. The vesicula seminalis is filled with sperms, and lies as in the previous species immediately behind the hindmost testis with its anterior dilated part interposed between it and the ovary in the median line. It is pear-shaped with the narrow tubular part directed to the left side towards the genital opening, where it enters the small cirrus sac; anteriorly it is overlapped for the greater part of its length by the left half of the dorsally situated ovary. The cirrus sac, 0˙18 in length and 0˙045 in maximum breadth, is tubular, commencing a little behind the ovary, at about the level of the receptaculum seminis near the left caecum. It contains inside a small portion of the vesicula seminalis, constricted off from the larger distally situated ductus ejaculatorius filled with sperms. The genital opening lies to the left side, a little behind the receptaculum seminis, at a distance of 0˙35 from the hinder end beneath the left caecum, where the latter slightly bends outwards to form the inconspicuous genital loop.

The ovary lies median or slightly to the right side with its outer wall close inside the right caecum, closely behind the hindmost testis, at a distance of 0˙5—0˙58 from the hinder end, i.e., about one fifth body length from it. It is divided into four or five lobes, and has nearly equal long and broad diameters, measuring 0˙17—0˙2 by 0˙17—0˙2 in size. The oviduct originates from the middle of the hinder margin of the ovary, and runs for a short distance before it joins the oval or spherical receptaculum seminis filled with sperms. The receptaculum seminis, 0˙072—0˙8 × 0˙09 in size, lies closely behind the ovary, to the right side near the right caecum, at 0˙43 distance in front of the hinder end. The oviduct leaves the receptaculum seminis at the hinder end near its outer margin, and passes a little backwards to the median line behind the level of the genital opening to join the narrow anterior end of the vitelline reservoir; soon after it sharply turns on itself to continue forwards as the prominent uterus, distended with the single ovum contained in it. The uterus lies transversely as in the previous species, a little behind the receptaculum seminis to the left side, and terminates into the short narrow metraterm, which opens to the exterior at the genital opening. Laurer's canal is very small and inconspicuous. The shell gland cells are absent. The

ovum is large, non-operculated and oval without filaments, measuring 0˙136 in length and 0˙095 in maximum breadth.

The vitellaria are well developed, extending from about the middle of the oesophagus, *i.e.,* from the anterior limits of the anterior loops of the caeca to a little in front of the hinder end of the body. They are composed of follicles of fairly large size, restricted mostly to the extracaecal region and overlapping the caeca at places. The follicles hardly extend inside the caeca, except behind the vitelline reservoir and in the region of the anterior loops, where they tend to meet in the median line. The transverse vitelline ducts arise obliquely, the right one at about the level of the genital opening and the left one a little behind it, and unite just behind the uterus near the ventral body wall to form the vitelline reservoir, which ends blindly to the left side near the left caecum.

*Plasmiorchis pellucidus* is distinguished from *P. orientalis* in a number of important features. The ventral sucker is absent in mature specimens; its position, however, can be easily determined by the presence of a clear transparent region free from the parenchyma, which is called the ventral sucker area. The testes are larger in number and are entire or slightly lobed, whereas in *P. orientalis* they are much lobed and lie quite apart from one another, filling almost the entire breadth of the intracaecal region. The length of the oesophagus and the anterior loops of the caeca is greater in *P. pellucidus* than in the other species. The vitelline follicles are mostly restricted to the extracaecal areas and do not enter the intracaecal region outside the testes as in *P. orientalis*.

Host—*Kachuga dhongoka.*

Habitat—Ventricle of heart.

Locality—Allahabad, India

## Plasmiorchis hardellii sp. n.

### (Figs 3, 6, 11, 12, 13)

These blood flukes were collected in November and December 1931 and August 1932 from the ventricle of the heart and aortic arches of the water tortoises *Hardella thurgi,* which are not commonly available at Allahabad. Out of the five tortoises examined three were found infected, with nine, one and five parasites each; of these we possess nine specimens in entire mounts and others in longitudinal and transverse sections. When freed in normal salt solution they move slowly with gliding movements. The body is thin, transparent, elongated and elliptical in shape with rounded anterior and posterior ends; the anterior end is generally broader and more rounded, but sometimes it is bluntly pointed on account of the partly protruding oral sucker. The size is larger than that of the other species, measuring in entire

TABLE SHOWING MEASUREMENTS OF *Plasmiorchis hardellii.*

| | Length of body. | Breadth in the region of ventral sucker. | Greatest breadth. | Oral sucker. | Ventral sucker. | Length in front of ventral sucker. | Length behind ventral sucker. | Genital opening: distance in front of hinder end. | Ovary: distance in front of hinder end. |
|---|---|---|---|---|---|---|---|---|---|
| 1. | 5·28 | 1·36 | 1·57 | 0·24 × 0·176 | 0·41 × 0·64 | 1·44 | 3·42 | 0·62 | 0·75 |
| 2. | 5·15 | 1·23 | 1·39 | 0·22 × 0·176 | 0·38 × 0·57 | 1·44 | 3·33 | 0·6 | 0·72 |
| 3. | 4·38 | 1·02 | 1·34 | 0·16 × 0·128 | 0·304 × 0·368 | 1·23 | 2·816 | 0·624 | 0·672 |
| 4. | 4·53 | 1·104 | 1·06 | 0·24 × 0·192 | 0·37 × 0·48 | 1·12 | 3·04 | 0·45 | 0·529 |
| 5. | 3·85 | 1·088 | 1·18 | 0·21 × 0·176 | 0·368 × 0·48 | 1·12 | 2·37 | 0·38 | 0·45 |

F, 2

mounts 3·85—5·28 in length and 1·18—1·57 in maximum breadth, which lies in the region midway between the ventral sucker and the ovary, *i.e.*, about the middle of the body length. The body wall has a thin muscular layer, which is covered outside by a thin cuticle. It is devoid of papillae, but it is armed with fine needle-like spines, which hardly project outside it.

The oral sucker is longer than broad and slightly protrusible, measuring ordinarily 0·24 in length and 0·176 in maximum breadth; in one specimen it measured 0·16 by 0·13 and in another 0·21 by 0·19 in size. The ventral sucker is broader than long and about double the size of the oral sucker, measuring 0·3—0·4 in length and 0·36—0·64 in maximum breadth. It is muscular, having a well developed layer of radial muscles with an outer thin layer of longitudinal muscle fibres, and lies 0·29 distance behind the intestinal bifurcation, at about one third body length from the anterior end. Its exact position can be seen from the table in which the length of the body in front and behind it is given in specimens of different lengths. The pharynx is absent. The oesophagus is long and slightly undulating with two or three bends, measuring 0·67— 0·96 in length, *i.e.*, one fifth to one sixth part of the body length. It gradually increases in breadth towards the hinder end, and is surrounded by deeply staining salivary gland cells, which are found in much larger numbers around its hinder part. Its inner wall is plicated as in the other species The oesophageal vesicle is well developed. The intestinal caeca arise at the junction of the vesicle with the oesophagus, and soon turn forwards to form the characteristic loops as described in the other species, which run parallel to the oesophagus for about the posterier three fourth of its length. The caeca of a much narrower calibre than the oesophagus possess small irregular diverticula, and form well defined loops in the region of the genital opening, close behind the ovary, before they terminate near the hinder end of the body. The genital loop formed by the left caecum has a characteristic semicircular shape, and is much wider than the corresponding loop of the right caecum, which lies closely behind the ovary with the bend directed inwards. These loops are specially well developed in this species; their hinder border marks out the anterior limit of the region, in which the glandular sac lies.

The excretory opening lies dorsal a little in front of the hinder end. The excretory bladder has a very short median stem, which bifurcates into two long narrow ducts running one on each side outside the caeca throughout the body length. The glandular vesicle is a large convoluted tubular mass, occupying the entire intracaecal space behind the genital loops of the caeca, *i.e.*, behind the ovary and the genital opening, and measuring 0·54 in length and 0·51 in maximum breadth near its anterior end. The presence of a large convoluted glandular vesicle, which is closely pressed against the walls of the caeca near their blind ends is a distinctive feature of this species. Histologically the walls of this tubular mass consist of an epithelium of cells, which

have lost their outlines and in most cases their nuclei; a few nuclei are, however, present in a degenerate condition here and there in the epithelium, which is apparently converted into a secretion. The secretion also fills the lumen of the vesicle in adult specimens. There is no muscular layer outside the epithelium. The glandular tubular mass ends blindly in the body, and is not of the nature of a lymph receptacle. It appears to be an important gland, which secretes a fluid of a colloidal nature, to be possibly absorbed within the body for some unknown physiological needs of the animal.

The nervous system resembles closely that of the other species. The oesophageal commissure, conspicuous in entire mounts, lies close in front of the anterior limits of the anterior loops of the intestinal caeca, 0.21 distance behind the anterior end of the oesophagus and 0.41 behind the anterior end of the body.

The testes, 19—21 in number, lie in a linear series in the median line, 0.064 – 0.096 distance behind one another, separated on either side by a moderate distance from the corresponding intestinal caecum. They are much broader than long with a characteristic band-like irregular form, narrow antero-posteriorly, thicker in the middle, pointed or somewhat notched at their lateral ends, and produced into one or two very short-pointed outgrowths near the middle region. Four or five anterior and a few posterior testes have the smallest breadth, measuring 0.032—0.1 in length and 0.24 – 0.27 in greatest breadth. The largest testes, situated about the middle of the row measure 0.032 in length and 0.4 – 0.48 in maximum breadth. The foremost testis lies a little distance behind the ventral sucker (0.128 behind it) and a little behind one third body length from the anterior end; the hindmost testis lies a little in front of the ovary and at a distance of 0.88 from the posterior end of the body. The testicular area occupies a little less than half the length of the body. In immature specimens the testes are seen developing in irregular chink-like spaces, marked out in the central deeply staining body parenchyma behind the ventral sucker. The vas deferens is absent and the vesicula seminalis poorly developed. In none of my specimens the latter is visible on account of the absence of sperms in it; it is represented, however, by a small median space between the hindmost testis and the cirrus sac. The cirrus sac is large, and unlike that of the other species has thick muscular walls composed of an inner layer of longitudinal and outer layer of circular muscle fibres. It is situated obliquely with the basal end near the median line just in front of or in level with the anterior margin of the ovary, a little behind the hindmost testis, and the terminal end to the left side close inside the left caecum within the region enclosed by its genital loop, 0.16 distance from the left body margin, and 0.5 0.67 distance in front of the hinder end.

The ovary lies to the right side closely inside the right caecum, 0.112 behind the hindmost testis and one fifth to one seventh part of the body

length in front of the hinder end, 0˙45—0˙75 in front of the latter.    It is irregu-
larly lobed and small in size, measuring 0˙075—0˙08 in length and 0˙09—0˙2 in
maximum breadth.    The oviduct arises from its inner margin, and runs back-
wards for a short distance to become enlarged into the receptaculum seminis,
which in most of the specimens is not filled with sperms.    The receptaculum
seminis is somewhat pear-shaped, measuring 0˙072—0˙075 in length and
0˙03—0˙033 in maximum breadth. It becomes narrowed at its hinder end to pass
into the uterus, which runs transversely from the median line to the left side.
The uterus, 0˙108 in length and 0˙021—0˙024 in breadth, is thin walled lined with
parenchymatous cells, and passes at its terminal end into the metraterm of
0˙108 length, which is lined internally with a thin cuticular layer, and shows
peculiar elevations and depressions of its modified epithelium devoid of nuclei.
The metraterm, however, is devoid of a muscular layer except in the small
terminal part, the muscular tube, which is covered by a strongly developed
musculature, functioning as a sphincter; the latter has no epithelial layer inside,
and runs vertically downwards to open at the genital opening.    The shell
gland cells are absent.    A small inconspicuous Laurer's canal is present.    The
ovum is large, elongated oval in shape, and non-operculated without filaments,
measuring 0˙081 in length and 0˙03 in greatest breadth.    Only one ovum is
contained at a time in the uterus or the metraterm.

The vitellaria are well developed in a few specimens in my collection.
They are situated laterally as in the other species, commencing a little in front
of the middle of the oesophagus and terminating at the blind ends of the
caeca.    The follicles are smaller than those of the other species and are mostly
aggregated outside the caeca, extending slightly inwards in the lateral areas
outside the testicular zone.    The transverse vitelline ducts lie just in front of
the convoluted glandular vesicle, the right immediately behind the ovary and
the left a little further behind.    The vitelline reservoir lies immediately
behind the transverse ducts in the median line, ending blindly just in front of
the glandular vesicle.    A fairly large number of specimens possessed the
testes, cirrus sac, ovary, uterus and metraterm, but they lacked the vitellaria,
which were obviously not developed.    In a few specimens the latter were
found developing as a mass of nuclei situated here and there in the extracaecal
and intracaecal areas.    The vesicula seminalis and receptaculum seminis
were free from sperms in these relatively immature worms.

*Plasmiorchis hardellii* is distinguished from the other species in the
large size and shape of the body, characteristic irregular shape of the testes,
enormous development of the convoluted glandular vesicle, large size of the
cirrus sac, small size of the ovary, slight development of the vesicula seminalis
and presence of large well marked genital loops of the caeca in the region of
the genital opening.    The cirrus sac has thick muscular walls, while its
musculature in the other species is weakly developed as in the genus

*Spirorchis*. The vitellaria are composed of follicles of small size. The metraterm is characterised by the presence of a highly modified epithelium showing elevations and depressions. It is devoid of musculature except in the terminal part, which has a strongly developed musculature functioning as a sphincter. The intestinal caeca have indented margins or small diverticula throughout their course.

Habitat—ventricle of heart and aortic arches.

Host — *Hardella thurgi*.

Locality—Allahabad, India.

## Plasmiorchis obscurum sp. n.

(Fig. 7)

Three immature specimens of this species were obtained from the ventricle of the heart of two specimens of *Kachuga dhongoka*, one from one host and two from the other. Body length 3—3'2, maximum breadth 0'64 about the middle of body length; breadth in the region of ventral sucker 0'5. Body thin, transparent, elongated and spindle-shaped with bluntly pointed ends, broader near the anterior than near the posterior end. Suckers well developed. Oral sucker oval, entirely protrusible and twice as long as broad, measuring 0'176 × 0'08 Ventral sucker a little in front of one third body length, circular in outline, 0'144 in diameter. Pharynx absent. Oesophagus long, slightly undulating, nearly straight in the extended condition, 0'56 in length and 0'128 in maximum breadth, surrounded by salivary glad cells. Oesophageal vesicle well developed, 0'096 in length and 0'128 in breadth, ending 0'144 distance in front of ventral sucker. Anterior loops of intestinal caeca one on each side of oesophagus as in the other species, 0'384 in length. Intestinal caeca approaching towards each other and slightly undulating near their hinder end, with small outgrowths given off mainly from the inner walls and ending a little in front of the hinder end. A small, tubular, nearly straight glandular vesicle present in the median line at the hinder end of the body. Excretory bladder with a very short median stem bifurcating just behind the glandular vesicle into two long narrow ducts extending throughout the body length outside the intestinal caeca.

Intracaecal region between oesophageal pouch and rudiment of ovary a deeply staining mass of cells with rudiments of testes lying in a series in the median line. Testes rudimentary and hence small in size, about nineteen in number, separated from one another by 0'048 –0'08 distance; posterior testes situated nearer one another than anterior testis. Ovary small and rudimentary. Vitellaria not yet developed.

The specimens though sexually immature with poorly developed genital organs, show certain well marked features, in which they are distinguishable

from the other species, such as the shape of the body, intestinal caeca undulating near the hinder end and provided with small outgrowths and large number of testes. This species differs from *P. hardellii* in size, shape of body, presence of a small glandular vesicle and in the size of the suckers and oesophagus. It comes nearer *P. orientalis* in shape and size of the body, presence of two suckers, size of ventral sucker, length of oesophagus and small size of glandular vesicle, but it differs in the intestinal caeca, which are undulating near the hinder end and possess small outgrowths. Moreover, it has a much larger number of testes than *P. orientalis*.

Habitat—Vertricle of heart.

Host—*Kachuga dhongoka*.

Locality—Allahabad, India.

## Diagnosis of the Genus **Plasmiorchis** N. G.

Spirorchinae: Hermaphrodite distome blood flukes; delicate musculature. Body thin, elongated, flattened, narrow and elliptical or spindle shaped as in *Spirorchis*; body wall covered with very thin cuticle having fine needle like spines hardly projecting outside it. Oral sucker oval and protrusible; ventral sucker present (absent only in adult *Plasmiorchis pellucidus,* though ventral sucker area present), situated at about one third body length from anterior end. Pharynx absent; oesophagus long, about one fifth to one sixth length of body, sinuous with two to four bends and surrounded by salivary gland cells, which are numerous near its hinder end; inner wall of oesophagus plicated; small median pocket the oesophageal vesicle present at the point of intestinal bifurcation a little in front of ventral sucker. Intestinal caeca do not pass laterally as they arise, but turn abruptly forwards for one third to three fourths length of oesophagus and then bend backwards to form forwardly directed U-shaped loops, one on each side, continuing their course backwards almost to posterior end of body and forming small or well marked loops, specially the left caecum, in the region of genital pore. Genital opening ventral to the left side, beneath or close inside left intestinal caecum, behind ovary and a little in front of hinder end. Testes in a large number, arranged in a linear series in the median plane in the intracaecal area, behind ventral sucker and in front of ovary, usually irregularly lobed and of varying shapes; testicular area occupies a little less than half the length of body; vas deferens absent; vesicula seminalis usually well developed, filled with sperms and pear-shaped with its widest anterior end in contact with the hindmost testis. Cirrus sac extremely small with weak musculature except in *P. hardellii*, in which it is fairly large with stout musculature (vesicula seminalis small in this species); vesicula seminalis interna and ductus ejaculatorious present. Ovary lobed, median or slightly to the right, immediately behind hindmost testis,

about one fifth body length in front of hinder end ; receptaculum seminis oval or rounded immediately behind ovary ; uterus very short distinguished by the presence of a single large ovum, just behind receptaculum seminis ; metraterm very short. Laurer's canal present and shell gland cells absent. Transverse vitelline ducts slantingly situated, right a little in front of the left one, immediately behind uterus ; yolk reservoir behind transverse ducts, ending blindly to the left side. Vitellaria voluminous and situated laterally, extending from about middle of oesophagus, i.e., from anterior limits of forwardly directed loops of caeca to posterior end of body, outside or surrounding intestinal caeca. Excretory opening slightly dorsal at posterior end ; excretory bladder with a very small median stem bifurcating into two long narrow ducts, one on each side of body outside caeca. Glandular vesicle in the form of a tubular mass usually present near hinder end behind ovary and genital pore.

Habitat—Ventricle of heart and main arteries.

Host—Water tortoises, *Kachuga dhongoka* and *Hardella thurgi*.

Locality—Allahabad, India.

*Type species—Plasmiorchis orientalis* sp. n.

## Remarks on the Systematic Position of the Genus Plasmiorchis N. G., the Synonymy of Certain Genera and Classification of the Family Spirorchidae.

The genus *Plasmiorchis* belongs to the family Spirorchidae and the subfamily Spirorchinae, bearing a close relationship to the genus *Spirorchis* MacCallum 1918. It resembles the latter genus in the position and large number of testes, which lie in a linear series in the median plane, in the intracaecal area in front of the ovary and the genital pore. The vas deferens is absent, vesicula seminalis well developed and the cirrus sac small with poorly developed musculature as in *Spirorchis*. In *P. hardellii,* however, the vesicula seminalis is small and the cirrus sac relatively larger with strongly developed musculature. The ovary is always lobed and occupies the same position in the two genera, i.e., median or slightly to the right, a little behind the hindmost testis. The size and position of the receptaculum seminis, uterus, vitelline ducts and vitelline reservoir are similar. The ovum is discharged singly and is without filaments. The vitellaria are voluminous and lateral; there is a close resemblance in the excretory system of the two genera. The glandular vesicle is also present near the hinder end of the body in both. The important features in which *Plasmiorchis* differs from *Spirorchis* are the presence of a ventral sucker (ventral sucker though absent in adult *P. pellucidus* is represented by a definite zone, the ventral sucker area) and forwardly directed loops at the origin of the intestinal caeca, one on each side of the oesophagus. It also differs in certain minor characters such as the

more forward extension of the vitellaria, which commence from about the middle of the oesophagus and the position of the genital opening, which lies a little behind the ovary and not in level with its caudal margin as in *Spirorchis*. The left intestinal caecum in *Plasmiorchis* gives off a loop, the genital loop in the region of the genital opening enclosing a space in which the cirrus sac and metraterm lie.

The genera *Henotosoma* Stunkard, 1922 and *Haematotrema* Stunkard, 1923 should be considered synonymous with the genus *Spirorchis*, which they resemble in the entire anatomy and topography of organs. The testes in these genera are large in number, and arranged in a linear series as in *Spirorchis*. The position of the ovary and the genital opening is also similar. The intestinal caeca arise just before the posterior end of the oesophagus and pass lateral about one half of the distance to the body wall, before they turn backwards, extending almost to the posterior end as in *Spirorchis*. They are also monostomes, lacking the ventral sucker. The only character in which they differ from the latter genus is the position of the testes in the posterior half of the worm. There are some minor points of difference between *Henotosoma* and *Haematotrema* in the number of testes and position of the genital pore; in the former the testes are ten in number, and in the latter four, situated in the anterior part of the posterior half of the body. The genital pore in *Haematotrema* lies a little in front of that in *Henotosoma*. In our opinion these differences are not important enough so as to be considered of generic rank, the genera *Henotosoma* and *Haematotrema*, therefore, are merged in the genus *Spirorchis*, the former reduced to *Spirorchis haematobium* (Stunkard, 1922) and the latter to *Spirorchis parvum* (Stunkard, 1923).

*Tremarhynchus indicus* Thapar, the account of which is published in June 1933 number of Helminthology, agrees closely in many features with the species of *Coeuritrema* described by me in May 1933. Both these genera possess two testes with the ovary between them, a large cirrus sac with the vesicula seminalis outside it, in front of the anterior testis and an eversible cirrus. The position of the genital pore in both the genera is sinistral and dorsal, close behind the ventral sucker near the middle of the body length. The important points of difference are the absence of receptaculum seminis, presence of shell glands and larger size of vitellaria in *Tremarhynchus*. Thapar makes no mention of the presence of salivary gland cells and metraterm in his species. The salivary gland cells are present without exception in all the families of blood flukes and it is impossible to believe that they are absent in *Tremarhynchus*. It appears likely that the vitellaria in the latter do not extend in front of the intestinal bifurcation and the salivary gland cells surrounding the oesophagus have been taken for the vitelline gland cells in that region. *Tremarhynchus indicus* resembles *Coeuritrema lyssimus* and *Coeuritrema odhnerensis* so closely that it is unlikely that the receptaculum

seminis, which is a characteristic feature of the latter two species, is absent in it. We also feel doubtful for the same reason about the existence of the shell gland cells and the absence of the metraterm in this species. Thapar's observation that in his species the two caeca run backwards to the posterior end as slender straight tubes except a little distance in front of the hinder end needs confirmation, because obviously the dorsal shifting of the genital pore in *Hapalorhynchus* and *Coeuritrema* has resulted in the formation of the characteristic loop of the left caecum, towards the median line in the region of the pore. Apart from these differences *Tryemarhynchus indicus* differs from the species of *Coeuritrema* in minor features of a specific nature such as the size and shape of the body, size of the suckers, size and shape of the testes, ovary, vesicula seminalis and cirrus sac. In view of the foregoing, *Tremarhynchus indicus* must be considered synonymous with *Coeuritrema* and included in the latter genus on the basis of priority under the name of *Coeuritrema indicus* (Thapar). The latter species resembles *C. odhnerensis* in the shape of its body, but it is about twice in length of the latter species, and also differs in the oral sucker being larger than the ventral sucker, a feature in which it resembles *C. lyssimus*. The testes in *C. odhnerensis* are not so deeply lobed as in *C. indicus* in which they are described as divided into follicles, though Thapar's figure shows them to be deeply lobed and not separated into pieces so as to deserve the name of follicular testes, as the term is ordinarily used. The vitellaria in both these species extend a little more forwards than in *C. lyssimus, i.e.,* in front of the ventral sucker as far as the intestinal bifurcation. *C. indicus* differs remarkably from the other species not only in the shape of its testes, but it also differs in the large size and position of its vesicula seminalis. The receptaculum seminis as mentioned above is presumed to be present in this species.

## Family Spirorchidae Stunkard, 1921.

Stunkard gave a classification of this family in 1921, creating the subfamilies Spirorchinae and Hapalotreminae In 1923 he gave a fuller account of the family assigning *Hapalotrema* Looss, 1899 and *Hapalorhynchus* Stunkard, 1922 to the subfamily Hapalotreminae and *Spirorchis* MacCallum, 1918, *Henotosoma* Stunkard, 1922 and *Haematotrema* Stunkard, 1923 to the subfamily Spirorchinae. The genera *Henotosoma* and *Haematotrema* are now held, as mentioned above, to be synonymous with the genus *Spirorchis*. Since 1923 many genera have been created and added to this family; it, therefore, appears necessary to revise the family and subfamily diagnosis, and give keys for the identification of the genera and species.

*Family diagnosis.*—Small delicate hermaphrodite blood flukes with poorly developed musculature; monostomes or distomes. Pharynx absent;

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oesophagus long, surrounded by salivary gland cells, which are numerous near its posterior extremity; intestinal caeca ending blindly near posterior end, with or without forwardly directed loops at their origin ; only one intestinal caecum present in *Unicaecum.* Genital opening sinistral, dorsal or ventral, about middle of body length or near hinder end. Testes two with ovary between them (*Hapalorhynchus, Coeuritrema*), divided into a large number of follicles forming two masses, one in front of and other behind ovary (*Hapalotrema*), one large undivided testis behind ovary (*Vasotrema*) in front of ovary (*Unicaecum*), divided into follicles all arranged in a linear series anterior to ovary (*Spirorchis, Plasmiorchis*) or last one or two follicles behind ovary (*Diarmostorchis, Spirhapalum*). Ovary usually lobed, median, to right or left side, a little behind middle, or near hinder end of body, or long and rolled in posterior part of body (*Unicaecum*) ; receptaculum seminis and Laurer's canal present or absent. Cirrus sac small, well developed or rarely absent (*Hapalorhynchus*) ; vesicula seminalis externa large ; protrusible cirrus well developed in some genera. Uterus short; metraterm poorly or strongly developed ; ovum large with or without polar filament or filaments, discharged singly. Vitellaria lateral and extensively developed. Excretory vesicle small, dividing almost immediately into lateral ducts. Parasites in blood of turtles.

**Type genus.—Spirorchis** MacCallum, 1918 (Syn. **Proparorchis** Ward, 1921).

### Key to the subfamilies of Spirorchidae.

1.  Genital pore and ovary near middle of body length.     *Hapalotreminae*
    Genital pore and ovary near hinder end .     .     .     .     .     . 2
2.  Testes arranged in a linear series all or except last
    one or two in front of ovary ; two intestinal caeca
    present     .     .     .     .     .     .     .     .     . *Spirorchinae*

    Testis one continuous lobed structure and not
    divided into follicles ; one intestinal caecum
    present .     .     .     .     .     .     .     .     . *Unicaecumiinae*

### Subfamily Hapalotreminae Stunkard, 1921.

*Subfamily diagnosis.*—Spirorchidae : Genital pore sinistral, dorsal rarely ventral, near middle of body length. Testes two with ovary between them (*Hapalorhynchus, Coeuritrema*), divided into two masses of follicles one in front and other behind ovary (*Hapalotrema*) or only one large postovarial testis present (*Vasotrema*). Ovary lobed, faintly lobed, or entire, slightly to left side, near genital pore and middle of body length. Cirrus sac well developed, absent only in *Hapalorhynchus*, in front of ovary or anterior testis. Vesicula seminalis large, outside cirrus sac; protrusible cirrus present, absent only in *Hapalorhynchus*. Receptaculum seminis and Laurer's canal present. Vitellaria well

developed extending from intestinal bifurcation or behind ventral sucker to caudal end of caeca. Parasites of turtles.

**Type genus.—Hapalotrema** looss, 1899.

### Key to the genera of the subfamily Hapalotreminae.

Testes divided into two masses, one in front of and
other behind ovary . . . . . . . *Hapalotrema*

Testes only two with ovary between them . . . . . 1

1. Cirrus sac and cirrus present . . . . . *Coeuritrema*

Cirrus sac and cirrus absent . . . . . *Hapalorhynchus*

Testis only one, behind ovary . . . . . *Vasotrema*

### Key to the species of the genus *Coeuritrema*

Ventral sucker smaller than oral sucker . . . *C. odhnerensis*

Ventral sucker larger than oral sucker . . . . . . 1

1. Body narrow, pointed at hinder end ; body length
3·16—3·45 ; vesicula seminalis large, 0·2 in length *C. indicus*

Body broad, somewhat rounded at hinder end; body
length 1·5—2 ; vesicula seminalis small, 0 048—0·057
in length . . . . . . . . *C. lyssimus*

## Subfamily Spirorchinae Stunkard, 1921.

*Subfamily diagnosis.*—Spirorchidae : Genital pore sinistral, ventral, near hinder end of body. Testes, large in number, arranged in a linear series in the intracaecal area all or except last one or two in front of ovary. Ovary lobed, dextral or median, near genital pore and hinder end of body. Cirrus sac small, with poorly developed musculature except in *Spirhapalum* and *Plasmiorchis hardellii*. Vesicula seminalis large, outside cirrus sac, with anterior end broad and in contact with hindmost testis. Receptaculum seminis and Laurer's canal present. Vitellaria both extra and intracaecal, extending from intestinal bifurcation or about middle of oesophagus to caudal end of caeca. Parasites of·turtles.

**Type genus.—Spirorchis** Mac Callum, 1918 'syn **Proparorchis** ward, 1921.)

### Key to the genera of the subfamily Spirorchinae.

Intestinal caeca with loops at their origin, one on
each side of oesophagus . . . . . *Plasmiorchis* N. G.

Intestinal caeca without loops at their origin . . . . . 1

1. Testes all in front of ovary . . . . . *Spirorchis*

One or two testes behind ovary . . . . . . 2

2 Ventral sucker present ; cirrus sac spacious . . *Spirhapalum*

Ventral sucker absent ; cirrus sac poorly developed *Diarmostorchis*

### Key to the species of the genus Spirorchis.

Testes commencing behind middle of body . . . . 1

Testes commencing in front of middle of body . . . . 2

1. Testes 4 or 5 in number ; genital pore at one fourth body length from posterior end  .   .   .    *S. parvum* (Stunkard, 1922)

    Testes 10 in number ; genital pore near posterior end  . . . . . . . . . *S. haematobium* (Stunkard, 1923)

2. • Genital pore one seventh of body length from posterior end  . . . . . . . . . . 3

    Genital pore one fourth of body length from posterior end  . . . . . . . . . . 4

3. Testes larger than ovary, not distinctly separated  .  *S. innominata*

    Testes smaller than ovary, distinctly separated   .  *S. artericola*

4. Testes large, commencing immediately behind intestinal bifurcation . . . . . . . *S scripta*

    Testes large, commencing some distance behind intestinal bifurcation . . . . , . *S. elegans*

    Testes small, not more than one half size of ovary .   *S. picta*

### Key to the species of the genus Plasmiorchis

Ventral sucker absent in adult, but ventral sucker area present  . . . . . . . *P. pellucidus*

Ventral sucker present  . . . . . . . . 1

1. Cirrus sac larger, with stout musculature . . . *P. hardellii*

    Cirrus sac very small, with weak musculature as in *Spirorchis*  . 2

2. Testes 5—7 in number ; caeca straight without outgrowths  . . . . . . . . *P. orientalis*

    Testes much larger in number; caeca undulating near posterior end and with small outgrowths  .   *P. obscurum*

### Subfamily Unicaecuminae, new subfamily

*Subfamily diagnosis.—* Spirorchida :—Only one intestinal caecum present, the other atrophied and absent. Testis one continuous lobed structure, and not divided into separate follicles; vas deferens arises from anterior end of testis and not from posterior extremity as in Spirorchinae ; vesicula seminalis very long, spirally coiled and parallel to testis throughout length of body. Ovary long and coiled in posterior part of body. Parasitis of turtles.

**Type genus.—Unicaecum** Stunkard, 1927.

### Discussion on the Relationships of the Families of Blood Flukes.

The relationships of the Spirorchidae with the Schistosomatidae have been discussed already (1933). The subfamily Hapalotreminae represents the ancestral blood flukes, from which have been evolved along one line the Schistosomatidae, and along another the degenerate suckerless blood flukes of the families Aporocotylidae and Sanguinicolidae. It is this latter part of the theme which we discuss further in this paper.

The highly interesting genera of blood flukes *Aporocotyle, Psettarium, Deontacylix* and *Sanguinicola* are unique among the Digenetic trematodes in having lost both the suckers. *Aporocotyle* was discovered by Odhner in 1900 as an ectoparasite from the gills of flounder. It was later announced by him in 1911 as a blood fluke. *Sanguinicola* was discovered by Plehn in 1905 as an endoparasitic Turbellarian, and included by her in a new family Rhynchostomida. Later in 1908 she considered it as a monozoic Cestode. Lühe in 1910 created for it a separate order of Cestoda, Rhynchostomida M. Plehn. Odhner in 1911 after comparing it fully with *Aporocotyle* and *Hapalotrema* recognised its true nature as a Digenetic trematode. He also reported in this paper that the suckerless *Deontacylix ovalis* Linton from the intestine of a West Indies fish may be a blood fluke, which in reality is a relation of *Sanguinicola*, and in regard to the structure of the gut occupies an intermediate position between it and *Aporocotyle*. In 1912 Odhner created for the blood parasites of *Aporocotyle—Sanguinicola* series a new family Aporocotylidae, which was accepted and defined by Stunkard in 1923. Woodland in 1923, on the basis of his erroneous description of the genital organs of *Sanguinicola* in the blood of Siluroids from Sudan, agreed with Plehn's first idea of regarding that genus as an aberrant and much modified Turbellarian, and denied entirely its Malacocotylean affinities. Odhner in 1924 pertinently corrected this idea after giving a correct description of the African species, which he named *S. chalmersi*. The morphology and development of the European species of *Sanguinicola* have been recently investigated by Ejsmont in 1926. Poche in 1925 and Fuhrmann in 1930 accepted the family Aporocotylidae for *Aporocotyle* and *Deontacylix* and the family Sanguinicolidae for *Sanguinicola* in the Digenea. The latter family was created by Graff in 1907, when *Sanguinicola* was included in the Turbellaria *Rasin in 1929 assigned a new genus *Janickia* to the Sanguinicolidae, to which has also been added by Van Cleave and Mueller in 1932 a new species *Sanguinicola occidentalis* obtained from the heart of *Stizostedion vitreum* from Oneida Lake. Layman in 1930 described a new species *Aporocotyle odhneri* in blood of *Spheroides borealis* from the Sea of Japan. In 1929 Goto and Ozaki discovered in the intestine of a puffer, *Plehnia japonica* which they called *Psettarium japonica* in 1930. The latter species, which is considered to be closely related to *Deontacylix* appears to be a blood fluke. As its discoverers had apparently recourse to only one specimen for description, its true habitat in mesentric blood vessels might have escaped their notice. Their statement that no blood corpuscles were found in the intestinal contents of the parasite does not seem to be a valid argument for denying its haematic abode, as Plehn in her first description had also stated that blood corpuscles were never found in the gut of *Sanguinicola*.

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* Biol. Spisy. Brno. 8, XVI, 1929.

From the account of morphology it is clear that we have a descending series in the evolution of the alimentary system of the four suckerless trematodes hitherto known, *Aporocotyle—Psettarium Deontacylix—Sanguinicola.* In all these genera the gut is of the basic H-shaped type. In *Aporocotyle* the oesophagus is of about the same length as in the Spirorchidae and Schistosomatidae; it is also surrounded as in these families by the salivary gland cells. The intestinal caeca are also of the same length and reach near the hind end. The only point of difference, however, is the presence of anterior blind sacs in *Aporocotyle.* The intestinal caeca of *Plasmiorchis* have got forwardly directed loops at their origin exactly in a similar position to that of the anterior blind sacs of the gut of the latter genus. There is a peculiar similarity of the gut in this feature in the two genera. We may say that the formation of loops by the caeca at their origin as in *Plasmiorchis* provides an appropriate condition for the origin of the blind sacs at the anterior ends of the caeca of *Aporocotyle.* From this it follows that *Plasmiorchis* is related to the ancestral blood fluke from which *Aporocotyle* is evolved. It appears that the evolution in the blood flukes, as in the rest of the Digenea, has taken place by mutations as displayed by certain basic tendencies. Just as an ancestral form like *Plasmiorchis* came into existence with loops at the origin of the caeca to provide for an increased absorptive surface for food, another form closely related to it arose in the Hapalotreminae having two limbs of the loop fused, as it were, to form the anterior blind sac of one side of the gut. From the gut of *Aporocotyle* can be derived that of *Psettarium* in which the oesophagus is long and opens in the centre of the H-shaped intestine. The anterior caeca are small, *i.e*, about one third as long as the oesophagus, but the posterior caeca are much smaller than those of *Aporocotyle,* terminating much in front of the hinder end. From *Aporocotyle* onwards there is a great tendency in this series of genera towards a reduction in the length of the intestinal caeca and from *Psettarium* onwards there is also a tendency towards a greater development of the anterior horns. This has culminated in the extremely small H-shaped gut of *Sanguinicola,* in which both the anterior and posterior horns are of nearly equal size *Deontacylix,* in this respect, occupies an intermediate position between *Psettarium* and *Sanguinicola.* It has posterior caeca much smaller and anterior caeca much larger than those of *Psettarium,* but they are both of nearly equal size as in *Sanguinicola,* though much larger than in the latter genus. Goto and Ozaki do not mention the presence of salivary gland cells in *Psettarium,* but we presume that they are present in this genus also. In *Sanguinicola chalmersi* the lobes of the H-shaped gut have lost their separate entity and the gut has consequently taken an irregular shape of the Rhabdocoele type. The mouth opening is extremely small in these blood-sucking genera.

There is a close similarity in the genital organs of these four genera. The testes in all of them are divided into a large number of follicles. It has been suggested in a previous paper that the ancestral blood fluke possessed two testes with the ovary between them like *Coeuritrema* and that the presence of a large number of testes in front of the ovary, which lies near the hind end as in the Spirorchinae and the Aporocotylidae, is a secondary condition evolved from the condition in the Hapalotreminae, in which the anterior testicular mass developed preponderantly, so that the ovary with its associated ducts and the genital pore came to lie near the hind end, whilst the posterior testis not possibly divided into follicles became entirely suppressed. In *Aporocotyle* the testes, large in number, occupy irregularly the entire intracaecal region between the intestinal bifurcation and the ovary; in the Spirorchinae they occupy the same position with this difference that their number is smaller and arrangement regular in a linear series. The former condition is primitive and the latter secondary. We are inclined to believe that *Aporocotyle* represents the origin of one-side branch and Spirorchinae as the other of the main stem represented by the common ancestor, in which the *Aporocotyle* arrangement of testes and ovary was present. In *Psettarium* and *Deontacylix* the testes lie both outside and inside the caeca, occupying nearly the entire space available, between the intestinal bifurcation and the ovary, on account of reduction in length of the caeca and their approachment towards each other near their origin. In *Sanguinicola*, however, their arrangement is somewhat regular in a double row, behind the gut and in front of the ovary, but this is obviously a departure from the irregular arrangement of *Aporocotyle* type along another direction from that, shown by the testes of *Psettarium* and *Deontacylix*. The shape of the ovary varies in different genera or even in different species of the same genus and should not be considered of much importance from the point of view of these relationships. It is spherical or ovoid in *Aporocotyle,* slightly lobed in *Deontacylix*, much lobed in several species of *Plasmiorchis* and *Spirorchis,* ramified or aciniform in *Psettarium* and H-shaped in *Sanguinicola.*

The genital pore or separate male and female openings in the suckerless genera lie dorsal to the left side (dorsal and nearly median in *Sanguinicola*) near posterior end. In the Hapalotreminae also the genital pore lies dorsal to the left side, though near the middle of the body length. This also supports the view mentioned above about the evolution of these forms from the Hapalotreminae. The Spirorchinae, in which the genital pore is ventral near the posterior end, represents obviously another line from the same common ancestor. The genus *Aporocotyle* among the genera of its own line stands closer to that ancestor, in that it has one opening for both male and female ducts, which lies in front of the ovary; whereas the other genera show a specialized condition in that the male and female openings are separate,

a condition which is not without its parallel in the Digenea. The cirrus sac in *Aporocotyle* is also fairly well developed, resembling that of the Hapalotreminae. Though it is smaller in *Psettarium* and *Deontacylix*, it is conical and bent as in the latter subfamily. A large vesicula seminalis outside the cirrus sac similar to that of the Spirorchidae is present in *Deontacylix*. The uterus in *Aporocotyle* and *Psettarium* is much larger than in the latter family consisting of a number of convolutions and containing a large number of ova. In *Deontacylix* it is much larger and filled with numerous ova. As in the Schistosomatidae the genus *Schistosoma* has secondarily developed a uterus containing a large number of ova, whereas its ancestors *Bilharziella*, *Ornithobilharzia*, *Austrobilharzia* and *Heterobilharzia* have a very small uterus containing only one ovum, in the same way *Aporocotyle*, *Psettarium* and *Deontacylix* have secondarily acquired a large uterus. In this respect *Sanguinicola* with a very small uterus containing only one ovum shows the primitive condition. The metraterm is well developed in *Aporocotyle* as in many Hapalotreminae. The vitellaria are extensively developed in the latter genus as in the Spirorchidae. In *Psettarium* they are still more extensive, occupying the entire ventral surface of the body from the anterior end to the ovary. In *Sanguinicola* they are also extensive; in *S. chalmersi* they extend posteriorly even behind the ovary. There is only one vitelline duct present in all these genera except *Sanguinicola occidentalis* the left one having disappeared as pointed out by Odhner

In the excretory, nervous and muscular systems also there is a substantial agreement not only between these four genera but also between them and the Spirorchidae. In the scheme of relationships of the blood-fluke families it appears certain, as shown above, that *Aporocotyle* stands near the Spirorchidae, and represents a close relation of the ancestor, from which are evolved along one line its closely related genera *Psettarium, Deontacylix* and *Sanguinicola* and along another the subfamily Spirorchinae. The genus *Unicaecum* has arisen as an aberrant branch from the latter subfamily, and we accordingly, include it in a new subfamily. *Aporocotyle, Psettarium* and *Deontacylix* are assigned to the family Aporocotylidae.

EXPLANATION OF THE PLATES.

Fig. 1.   Ventral view of *Plasmiorchis orientalis*.
Fig. 2.   Dorsal view of *P. pellucidus*.
Fig. 3.   Ventral view of *P. hardellii*.

Microphotographs

Fig. 4.   *P. orientalis*.   Leitz Eyepiece X; Leitz Objective I.
Fig. 5.   *P. pellucidus*.   Leitz Eyepiece X; Leitz Objective I.
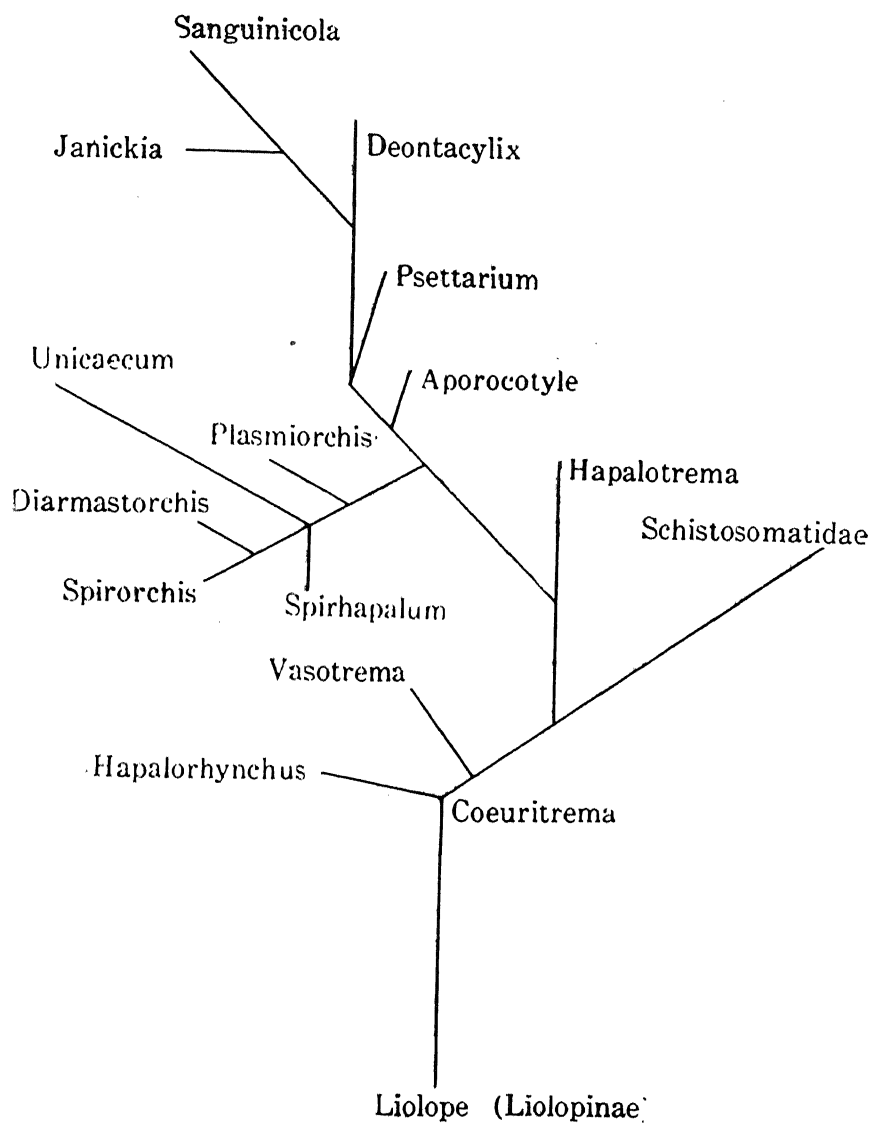
Tree indicating the probable phylogeny of the blood flukes

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Fig. 6.   *P. hardellii.*   Zeiss Eyepiece X; Leitz Objective I.

Fig. 7.   *P. obscurum.*   Leitz Eyepiece X; Leitz Objective I.

Fig. 8.   Immature specimen of *P. orientalis.*   Leitz Eyepiece X; Leitz Objective I.

Fig. 9.   T. s. of *P. orientalis* in the region of ventral sucker. Leitz Eyepiece 3; Leitz Objective 45 X.

Fig. 10.   Hinder part of body of *P. pellucidus*   Zeiss Eyepiece X; Leitz Objective 3 – 10 X.

Fig. 11.   Hinder part of body of *P. hardellii.*   Leitz Eyepiece 3; Leitz Objective 3-10 X.

Fig. 12.   Part of t. s. of *P. hardellii* in the region of cirrus sac. Leitz Eyepiece 3; Leitz Objective 3 10 X.

Fig. 13.   T. s of *P. hardellii* in the region of metraterm, cirrus sac and genital opening. Leitz Eyepiece 3; Leitz Objective I.

## LETTERING.

a. l. i. c, anterior loop of intestinal caecum ; c. s., cirrus sac ; e. v., excretory vesicle; g. l. i. c., genital loop of intestinal caecum; g. o., genital opening; g v, glandular vesicle; i. c., intestinal caecum; m., metraterm; o. s., oral sucker; oes., oesophagus; oes. v., oesophageal vesicle; ov., ovary; r. s, receptaculum seminis; t., testis; ut. uterus; v. s, ventral sucker; v. r., vitelline reservoir; v. s. a., ventral sucker area; v. sm., vesicula seminalis; vit., vitellaria.

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**Errata in Part I Published in *Bull Acad. Sc. U. P., Allahabad.* Vol 2, No. 4, May 1933:—**

Page 207, line 19 for " distel " read distal.

Page 209, line 2 from bottom add between " right intestinal caecum " and " by the intervening metraterm " the following,-separated from the left caecum.

Page 213, line 3 after *Henotosoma* Stunkard for " 1923 " read 1922.

Page 213, line 9 for " *Haemato rema* " read Hapalotrema.

Page 213, line 22 for " Proparorchidae " read Proparorchis.

Page ˀ21, line 12 for " Zoolopathologica " read Zoopathologica.

Page 221, line 17 for " Pein " read ein.

Page 221, line 19 for " (1921) " read (1912)

Plate I



Fig. 1                    Fig. 2
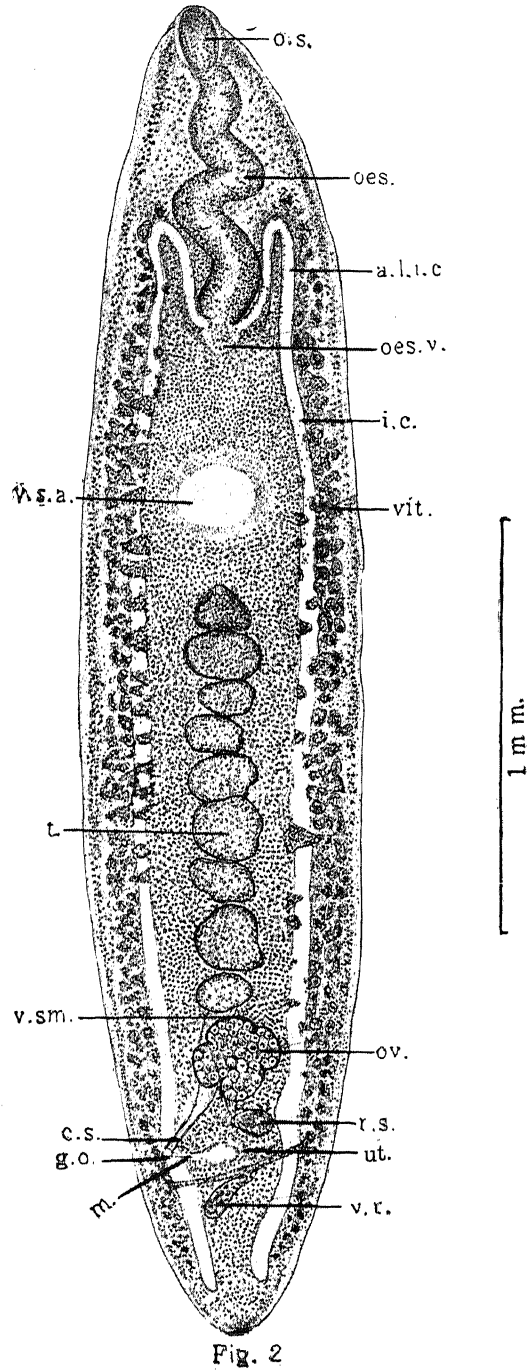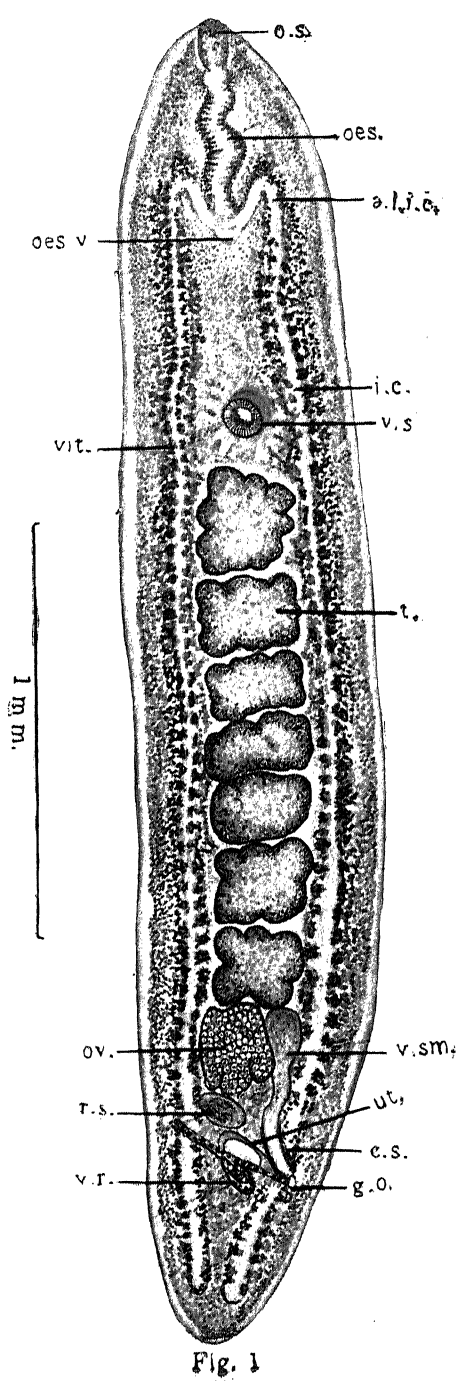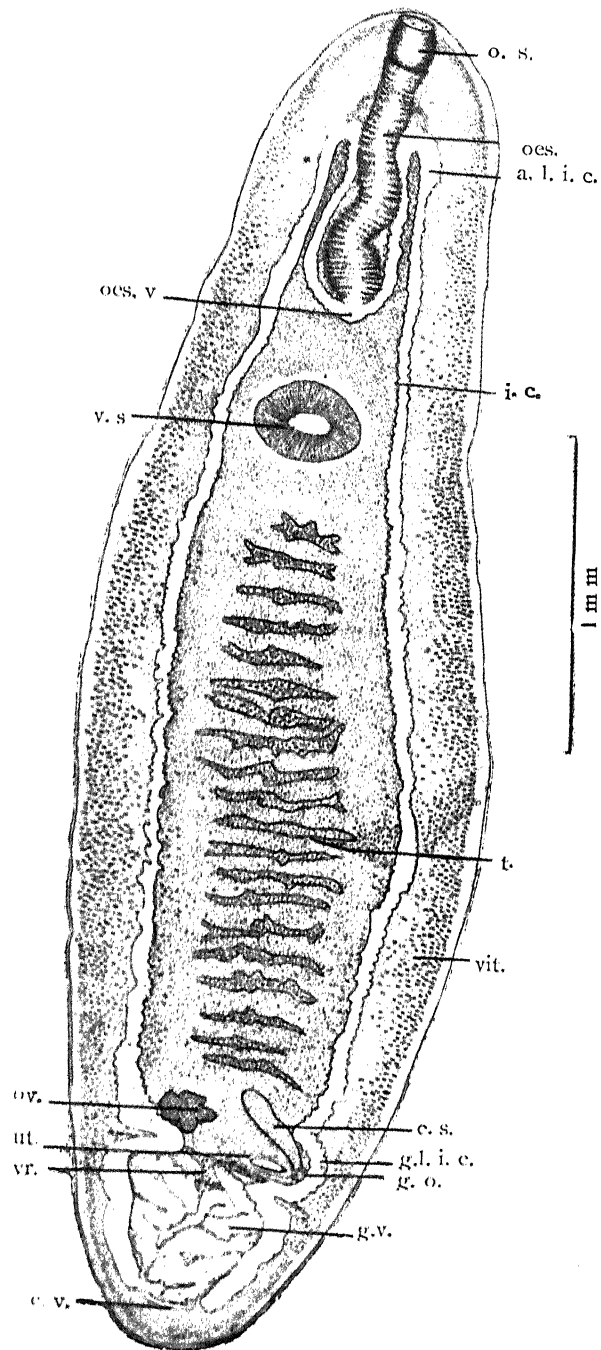
Plate II



Fig. 3

Plate III



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Plate IV









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12
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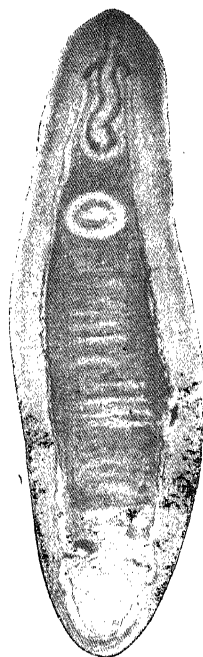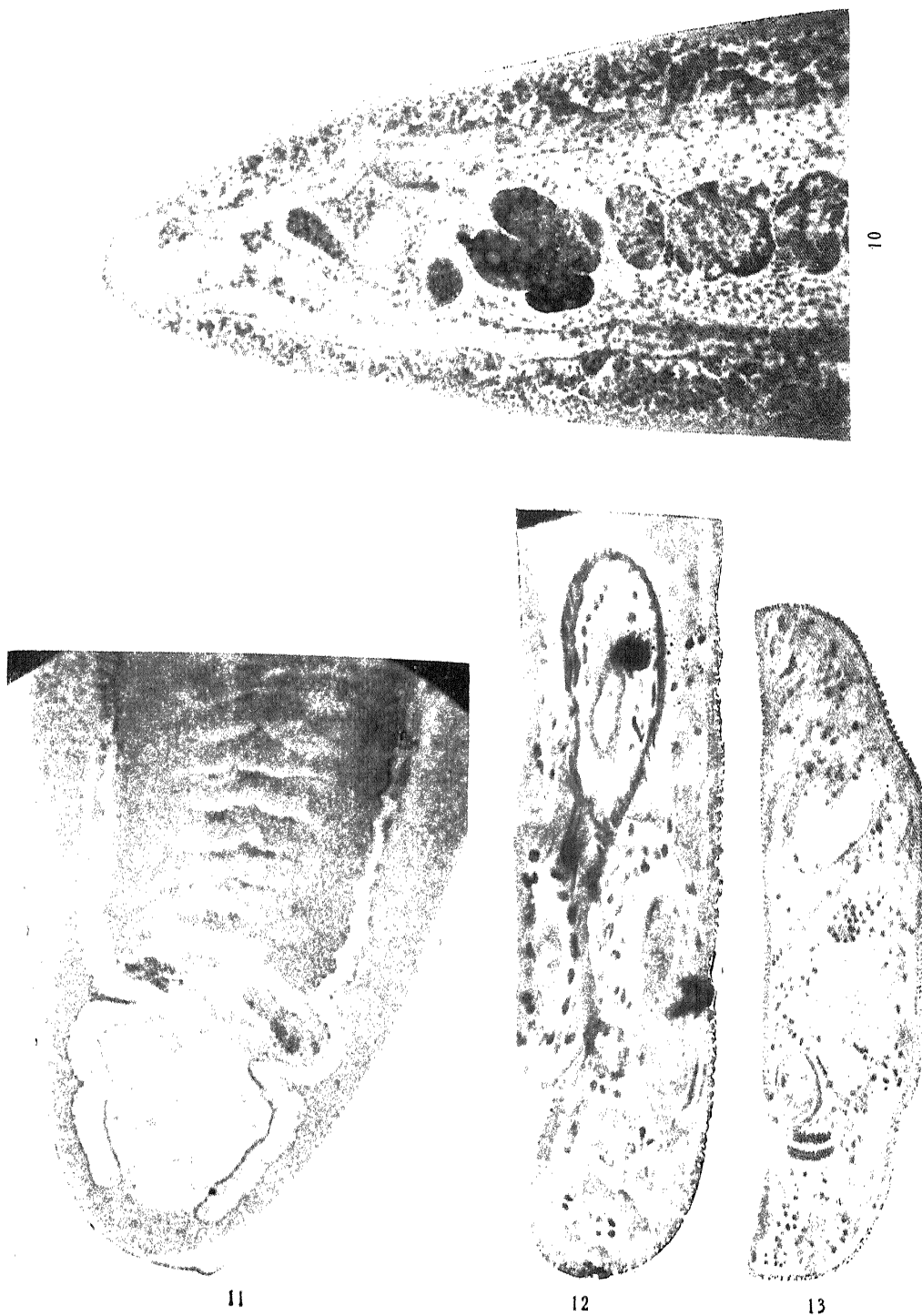
# ON THE ABSORPTION SPECTRUM OF NITROGEN MONOXIDE IN THE SCHUMANN REGION

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Communicated by Prof. M. N. Saha

Received December 14, 1933

The absorption spectrum of Nitrogen Monoxide was studied by Leifson[1] in the Schumann region and by Datta[2] in the quartz region. Leifson used a vacuum grating spectrograph and absorption cells with fluorite windows and worked chiefly between $\lambda 2400$ and $\lambda 1240$. The absorption column was 1·5 cms. in length with $N_2O$ at atmospheric pressure. He found two continuous absorption bands, the first extending from $\lambda 2000$ to $\lambda 1680$, and the second from $\lambda 1550$ to the limit of fluorite. But no explanation of these cuts were offered. Six years later Wulf and Melvin[3] performed some irradiation experiments with $N_2O$ and showed that it is photochemically decomposed by light of wavelength $\lambda 2300$ into NO and N. In 1932 Datta again studied the absorption of $N_2O$ in the quartz region, and tried to interpret his results from thermochemical data. He found $N_2O$ to absorb light continuously from a long wavelength limit and traced it with the aid of some microphotograms to $\lambda 2750$ which is much further on the long wavelength side than Wulf and Melvin's limit. Ascribing the beginning of absorption at $\lambda 2750$ to the photo-dissociation of $N_2O$ into NO and $N(^4S)$, as given in

$$N_2O + h\nu_1 = NO + N(^4S) \qquad . \qquad . \qquad . \qquad . \qquad (1)$$
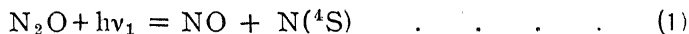
Datta calculated the heat of dissociation of $N_2$ with the aid of some thermochemical equations and obtained a value of 8·7 volts which agreed well with some other correct determinations of $D_{N_2}$. This proved the validity of assuming a process like (1).

At first sight this process seems to have no connection with Leifson's absorptions at $\lambda 2000$ and $\lambda 1550$. In this connection attention may be drawn to the cases of $SO_3^4$ and other higher oxides[5] and sulphides[6] and other

compounds in which a first absorption is generally followed by retransmitted patches of light with subsequent absorptions which correspond to liberation of atoms in metastable states. With $N_2O$ a similar behaviour should be expected with a second and third setting of absorption according to the following equations,

$$N_2O + h\nu_2 = NO + N(^2D) \quad . \quad . \quad . \quad . \quad (2)$$

$$N_2O + h\nu_3 = NO + N(^2P) \quad . \quad . \quad . \quad . \quad (3)$$
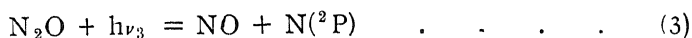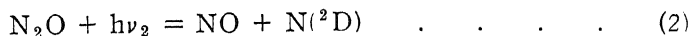
where $^2D$ and $^2P$ are the metastable states of nitrogen. Taking Compton and Boyce's[7] value of $^4S - ^2D$ of nitrogen, Datta identified the second of Leifson's limits at $\lambda 1550$ as indicating the decomposition of $N_2O$ into NO and N in the $^2D$-state, on the grounds that with the aid of microphotograms $\lambda 1550$ could be extended to $\lambda 1840$ which is the expected place. The following work in the Schumann region was performed with a view to verify this point.

## Experiment

I have used a fluorite prism spectrograph designed according to our own directions. The spectrograph has strong light gathering powers and the region $\lambda 2200$ to $\lambda 1300$ comes on a plate 10 cms. long. It is specially designed for absorption work in the Schumann region. The absorption chamber which was of glass was separate and could be sealed to the end of the spectrograph carrying the fluorite window. The spectrograph and the absorption chamber were evacuated separately by common Holweck molecular pump and in the line a discharge tube was connected to test the vacuum. To the other end of the absorption chamber a hydrogen tube (run by a 2KW transformer) with a fluorite window was joined by means of a wide bore pressure tube. Thus the fluorite windows of the hydrogen tube and the spectrograph were common to the absorption chamber also. The spectrum of hydrogen served as a continuous source of light up to $\lambda 1600$ after which the secondary emission spectrum of hydrogen appeared extending to the limit of fluorite. An idea of the vacuum in the chamber could be formed from the nature of the discharge in a vacuum tube attached to the spectrograph which was run by an induction coil.

It was found by trial that the length of the absorption chamber about 30 cms.) was too long for the present purpose, and therefore a separate absorption cell having a length of only 10 cms. had to be inserted into



Fig. 1

the main chamber. This cell carried as usual fluorite windows at the ends and

was also provided with a bent side tube so as to facilitate insertion in the main chamber. After the cell was filled with $N_2O$ dried with $P_2O_5$ at the requisite pressure the extreme end was sealed off. Fig. 2 shows the main absorption chamber and the subsidiary absorption cell in position. A
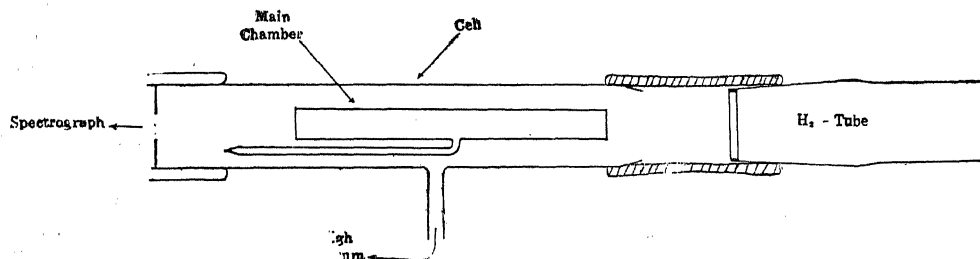


Fig. 2

series of different pressures were used ranging from ·05 cm. to 20 cms. and photographs taken on Schumann plates.

The development of the absorption spectrum was as follows. At very low pressures light was cut off at about λ 1850 and reappeared at about λ 1700 and was again cut off at about λ 1580. These absorptions were rather sharp in comparison to Datta's absorption in the quartz region. With increasing pressures the retransmitted patch of light from λ1700 to λ1580 vanished and only the absorption at λ1850 was visible. At still higher pressures the absorption at λ1850 began to extend towards longer wavelengths finally extending beyond λ2200. This was due to the fact that owing to heavy absorption, the retransmitted patches are wiped out.

## DISCUSSION

The first beginning of absorption was found by Datta to correspond to λ 2750. Now according to the second and third processes $h\nu_1 - h\nu_2$ and $h\nu_2 - h\nu_3$ should give approximate values of $^4S - ^2D$ and $^2D - ^2P$ of nitrogen, which, from the work of Compton and Boyce (loc. cit.) on the classification of arc spectrum of nitrogen are known to be 2·37 and 1·19 volts respectively. Since $h\nu_1$ is equal to the energy corresponding to λ 2750, that is, 4·53 volts, $h\nu_2$ should be 6·9 volts corresponding to λ 1800 and $h\nu_3$ should be 8·1 volts corresponding to λ1540. In the present experiment the first beginning of absorption at λ 1850 and the second at λ 1580 no doubt correspond to $h\nu_2$ and $h\nu_3$ respectively. The experimental value, therefore, are—

$$h\nu_{2750} - h\nu_{1850} = {}^4S - {}^2D \text{ of } N = 2·17 \text{ volts,}$$

$$h\nu_{1850} - h\nu_{1580} = {}^2D - {}^2P \text{ of } N = 1·13 \text{ volts.}$$

In some of these cases it seems that molecular spectra yield low values of the difference of atomic terms — this phenomenon is yet not satisfactorily

explained.   That the difference might not be the same as those obtained by the

arc spectrum could be under-
stood from the adjoining
potential energy diagram,
since we do not know the
nature of the upper curves.
This point has been discuss-
ed in the paper on the
sulphides of zinc, cadmium
and mercury.[8]

Now it has already been
mentioned that Datta identi-
fies Leifson's absorption at
λ 1550 as due to the inter-
action of a nitrogen atom in
the $^2$D state with NO. His
argument is based on the
grounds that since the first
absorption at λ 2750 is ex-
tended the second should
also be extended; and as

Fig. 3

Leifson has no doubt given the values of complete extinction of light at
λ 1550, this could be traced to λ 1840 nearly with the aid of microphotograms.
It might be remarked here that from the appearance of an extended absorp-
tion as a first cut one cannot predict that the subsequent absorptions will be
extended too.   In the present experiment it has been found that the absorp-
tions in the Schumann region are not at all extended and therefore it is highly
improbable for a shift of about 290 Å to take place by microphotograms.
Leifson's absorption at λ 1550 obviously corresponds to an interaction of NO
with a nitrogen atom in $^2$P state, and not $^2$D state as Datta holds.  Leifson
used a high pressure in his absorption cell, and this most probably accounts
for the absence of the second absorption at λ1850.   We generally come across
such peculiar behaviour of gases at different pressures.  It appears that the
absorption at λ 2000 obtained by Leifson is the same as λ1850 shifted towards
longer wavelengths due to high pressure.

In conclusion the author gratefully acknowledges the valuable guidance
rendered by Prof. M N. Saha, D.Sc., F.R.S.

## SUMMARY

Absorption experiments with $N_2O$ has been performed in the Schumann
region at different pressures.   It has been found that light is continuously cut
off at λ 1850, reappears at about λ1700 and is again cut off at λ 1580.   It is

suggested that the foregoing absorptions are due to photochemical dissocia-
tion of $N_2O$ into NO and nitrogen in the metastable states according to the
following—

$$N_2O + h\nu_{1850} = NO + N\,(^2D)$$

$$N_2O + h\nu_{1580} = NO + N\,(^2P).$$
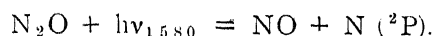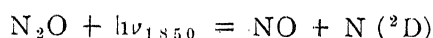
## SUPPLEMENT ADDED IN PROOF

On. of Datta's[2] curves for $N_2O$ in the quartz region has been reproduced
here. The point C corresponds to the long
wave beginning of absorption which marks
the photochemical dissociation of $N_2O$
into NO and N ($^4S$). But the curve has
rather a peculiar shape. It is not smooth,
but has a discontinuity at the point B.
The author[9] has shown elsewhere that a
discontinuity (or Kink) at any point of the
absorption curve has a special significance.
It has been shown that generally the main
curve is not a single one but composed
of two curves which have been drawn for
$N_2O$ here by dotted lines. In the figure
these are ABC and XYZ which are quite
distinct from each other.
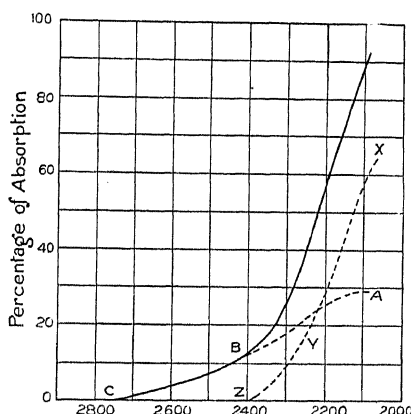


What is the process of dissociation of $N_2O$ when we get two beginnings
of absorption corresponding to two curves? This means that there are two
processes.

Light is thrown on this problem from a scrutiny of the structure of $N_2O$.
Various experiments on Dielectric constant have shown that while some of the
investigators have found the electric moment as zero, others find a small
positive value for it. The following models of $N_2O$ are possible—

(1)    N—O—N :—The bonds may be single or multiple. No electric
                moment is expected for such a model on account
                of symmetry.

(2)    $N\equiv N = O$ :—This model will show electric moment.

(3)    O        :—The O—N bonds are similar, but electric moment
      /  \         is possible.
    N — N

The study of absorption spectrum of $N_2O$ definitely rules out the sym-
metrical rod model for it, as in this case there is only one type of bond to be
severed. Corresponding to this splitting there will be only one absorption
curve. The figure shows that there are two beginnings of absorption which

F. 5

can only be explained if we suppose that there are two types of bonds present in $N_2O$ having different energies, as in model 2 or 3.

The curve XYZ may be attributed to a splitting of the N—O bond, the energy of which is given by Z, that is, $\lambda$ 2400$\equiv$5·2 volts nearly. And ABC will correspond to the breaking of the N—N bond with energy given by C, that is, $\lambda$ 2750$\equiv$4·5 volts.

In $CH_2Cl_2$, by splitting the absorption curves N. K. Saha[10] first obtained evidence of the rupture of two types of bonds C—H and C—Cl, the difference in energy of which agreed remarkably well with that obtained thermo-chemically.

In $TeO_3$ the structure is of the type shown from which we can expect only one smooth curve and no sign of kinks, as there is only one type of bond to be ruptured. This is borne out by experiment.[5]

$$\begin{array}{c} O \\ \parallel \\ Te \\ \diagup \backslash \\ O \quad O \end{array}$$
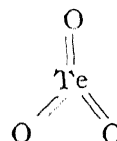
In a recent paper,[11] Prof. Watson and his co-workers have given an account of the determination of the electric moment of $N_2O$ and some other compounds. They have found a definite value for its electric moment which could not be decided by earlier measurements. The conclusion, they have drawn on the strength of their measurements regarding the structure of $N_2O$ agrees with that arrived at in the present paper independently.

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# ON THE ABSORPTION SPECTRA OF THE MONOXIDES
## OF THE ALKALINE EARTH METALS

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Communicated by Prof. M. N. Saha,

It has already been shown by the author in several papers that the action of light on diatomic compounds of the oxide group is similar to that of the Alkali Halides, first investigated by Franck[1] and his co-workers. If we represent any of these compounds by MX where M is a divalent metal and X an element of the oxygen group, then on illumination of the vapour of the oxide by light of suitable frequency, the molecule is dissociated into its constituent atoms. The energy involved may be calculated from the beginning of the continuous absorption. There may be further cuts corresponding to the dissociation of the molecule into its excited atoms.[2]

The emission band spectra of the Monoxides of the Alkaline Earth metals were studied by Mecke,[3] Mahanti[4] and others, who have shown that the bands are due to a $^1\Sigma \rightarrow ^1\Sigma$ transition. The present work deals with the absorption spectra of these oxides.

In a previous paper it has been shown that the oxides in the vapour state are polar compounds being formed of the ions $M^{++}$ and $X^{--}$ and it appeared from the interpretation of the absorption spectrum that light pulse as soon as it begins to be absorbed drives out both the electrons in $X^{--}$ to $M^{++}$ thus causing the oxide to be split up into M and X. In the present investigation I have tried to find whether the absorption by CaO, SrO and BaO can be interpreted in the same way.

## EXPERIMENT

It is well known that all these oxides are highly refractory. Mellor in his Treatise of Inorganic Chemistry writes, "........W. R. Mott estimated that the boiling points of CaO about 3400°C and those of SrO and BaO occur respectively at 3000°C and 2000°C ..." For absorption it is not necessary that we should have vapour at sufficiently high pressure almost equal to that of the atmosphere, below which absorption can be detected. In fact, Claassen and Veenemans[5] have been able to determine the vapour pressures of the compounds between 1600—1750°K for CaO, 1500—1650°K for SrO, and 1200—1500°K for BaO, the temperatures being taken above the absolute zero. It has

been pointed out by many workers in the field that with very high temperatures the beginning of absorption is shifted towards longer wavelengths. To avoid errors due to shift, therefore, it was thought advisable to stick to the ranges given by Claassen and Veenemans as nearly as possible

The substances were vaporised in the vacuum graphite furnace of our laboratory[6] in the presence of nitrogen at atmospheric pressure. The column of vapour was nearly 15 cms. long in each case. Silica tubes were used to hold the substances. The source of light was a Hydrogen discharge tube run by a 2 KW transformer, and the copper arc was used for comparison. Photographs were taken by means of an $E_3$ quartz spectrograph, on Schumann plates. To test the visible part of the spectrum a constant deviation spectrograph was used w th either Process plates or Panchromatic plates, where necessary. Exposures were of the order of 2 to 3 minutes.

## RESULTS

In every case the spectrum was found to be continuously cut off from a long wavelength limit, and there was no trace of bands. To locate the beginning of the continuous absorption microphotograms were taken by the microphotometer belonging to the Physics Department, Muslim University, Aligarh. Here I must mention that I am very thankful to Dr. R K. Asundi Reader in Physics there, for taking the microphotograms for me. On the same plate two exposures were given, that is, once the spot of light was allowed to run along the continuous spectrum and then the absorption spectrum.

Taking the ordinates of the continuous spectrum as 100 the percentage
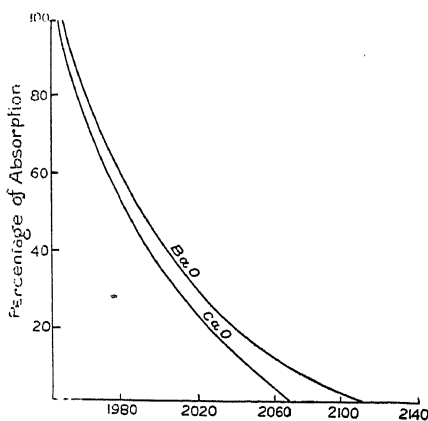


Fig. 1
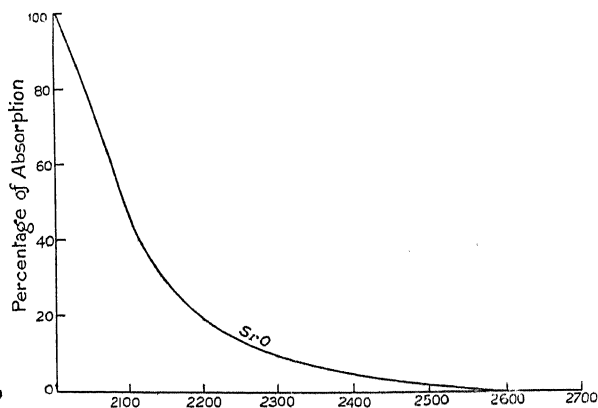


Fig. 2

of absorption was calculated from the absorption curves, and plotted with wavelength as abscissa. The point where such a curve meets the abscissa gives the beginning of absorption. From Figs. 1 and 2 we see that for CaO it is λ 2070, for BaO λ 2110, and for SrO λ 2600 A.

## CALCULATIONS

Taking R as the heat of dissociation of MX into M and X we get the following results from the Born Cycle, thermochemically.

Here $L_{MX}$ is the Latent Heat of vaporisation of [MX], and $L_M$ that of [M]  $D_{X_2}$ is the Heat of Dissociation of X .

Therefore,

$$R + L_{MX} = Q + \tfrac{1}{2}D_{X_2} + L_M$$
$$R = Q + \tfrac{1}{2}D_{X_2} + L_M - L_{MX}$$

The following table gives the values of the different quantities, the calculated values of R and the long wave limits of absorption from the graphs. The values of $L_{MX}$ have been taken from Claassen and Veenemans' paper, and other data from Landolt and Börnstein and other tables.
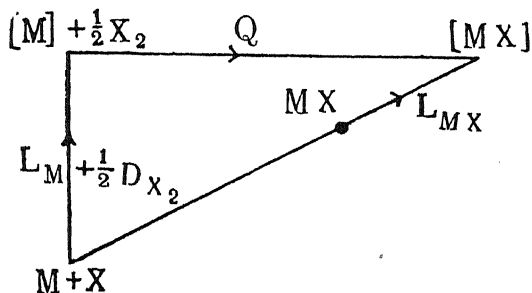


*Table I*

| MX | $Q$ k. cal. | $\tfrac{1}{2}D_{X_2}$ k. cal. | $L_M$ k. cal. | $L_{MX}$ k. cal. | R k. cal. | $h\nu$ |
|---|---|---|---|---|---|---|
| CaO | 145·0 | 64 | 44·2 | 120 | 133·0 | λ 2070 |
| SrO | 141·0 | 64 | 32·5 | 140 | 98·2 | λ 2600 |
| BaO | 125·9 | 64 | 32·4 | 90 | 132·3 | λ 2110 |

Now $R = \dfrac{Nh\nu}{J}$, and we see from Table I that there is fair agreement in the cases of CaO and BaO, but the wide divergence in the case of SrO leads one to doubt the correctness of the estimation of the latent heat of SrO. f we calculate indirectly from the long wave beginning of absorption, we find that $L_{SrO} = 128$ k. cal.

## DISCUSSION

The appearance of the continuous absorption at the end of the spectrum in each case shows that the long wave limit of absorption is due to a transition from a firmly bound ground state to an unstable excited state. In such a case when no bands are present the binding in the ground state is supposed

to be of the ionic type. In the solid state CaO, SrO and BaO form ionic lattices of the type of NaCl. With this view in mind, therefore, we should assign such an electron structure to a compound like CaO which is also consistent with its diamagnetic behaviour. This is afforded with the structure $Ca^{++}O^{--}$. Here $Ca^{++}$ and $O^{--}$ both have the configuration $[\ ]p^6$, where $[\ ]$ represents an inert gas core. The $^1S_0$ state which results from this configuration contributes nothing to magnetism.

Taking $Ca^{++}O^{--}$ as the normal structure of CaO in the ground state it is possible to calculate the energy required to dissociate CaO into Ca and O (normal), if the lattice energy is known. Born and Gerlach[7] calculated the value of the lattice energy in the following manner and applied it to the Born Cycle, to get the electron affinity of oxygen. Assuming the value of the electron affinity for oxygen we can utilise the Born Cycle to find the value of R.
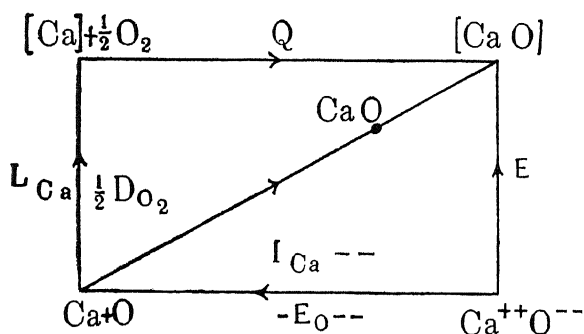


Here $I_{Ca++}$ is the sum of the ionisation potentials of Ca and $Ca^+$; $E_{O--}$ . . . the heat of formation of an $O^{--}$ ion out of O and 2 electrons. E . . the lattice energy. Hence,

$$R + L_{CaO} = E - I_{Ca++} + E_{O--}$$

The value of E has been calculated by Born and Gerlach by means of the following formula—

$$E = k. \frac{n-1}{n} . \sqrt[3]{\frac{\rho}{M}}$$

$$= 2450. \frac{n-1}{n}. \sqrt[3]{\frac{\rho}{M}}$$

where,    k = a constant involving Madelung's coefficient,
    n = the repulsion exponent,
    $\rho$ = the density,
    M = the molecular weight.

Here n is given by the formula,

$$n = 1 + C. \frac{1}{\chi}. \left(\frac{M}{\rho}\right)^{1/3}$$

where $\chi$ is the compressibility.

For CaO, SrO and BaO, $k = 2450$, but $\chi$ is unknown for all these compounds. Born and Gerlach have taken a rough estimate of $75 \times 10^{-12}$ which is a mean between $77 \times 10^{-12}$ for ZnO and $70 \times 10^{-12}$ for MgO.

Table II gives the values of the different quantities involved in calculating E and E' which is the value of the lattice energy calculated thermochemically from

$$E' = Q + L_{Ca} + \tfrac{1}{2}D_{O_2} + L_{Ca++} - E_O - -$$

*Table II*

| Substance | I k. cal. | E k. cal. | M k. cal. | $\rho$ | n | E k. cal. | E' k. cal. |
|-----------|-----------|-----------|-----------|--------|-----|-----------|------------|
| CaO ... | 411·7 | 49 | 56·1 | 3·25 | 5·93 | 800 | 714 |
| SrO ... | 383·0 | 49 | 103·6 | 4·34 | 9·12 | 758 | 670 |
| BaO ... | 348·2 | 49 | 153·3 | 5·30 | 11·40 | 728 | 620 |

It is evident that the values of lattice energy calculated from Born's equation (2) are higher than those calculated thermochemically from Born Cycle by 10 to 15 per cent. This leads to the conclusion that the assumption of approximate values of the compressibilities is wrong.

It is worth while mentioning at this place the extension made by Slater[8] in the calculation of the lattice energies of alkali halides. Slater has determined the change of compressibility with temperature and extrapolated the values to the absolute zero. In some cases the values of the compressibility at absolute zero differ appreciably from those determined at room temperature, and, therefore, the energies of lattice will change a good deal. But according to Slater, the representation of the potential energy in Born's equation $E = A + \dfrac{B}{r^n}$ by a single inverse term is erroneous. He, therefore, developed a series in terms of the change of compressibility with temperature and pressure, and recalculated the values of lattice energies which hardly differ from those obtained from Born's formula by 1 per cent. Since the dependence of compressibility on temperature has not been stated in a simple way, it is not possible to say whether Slater's values are better than those determined by Born's formula, as Hund has mentioned. Hence it is not possible to check the values of lattice energy unless an experimental determination is made of the compressibilities.

## CONCLUSION

The calculations show that the behaviour of CaO, SrO and BaO in the presence of light is similar to those of the oxides and sulphides investigated

by the author. That is, the continuous absorption is due to the simultaneous transition of both the electrons in $X^{--}$ to $M^{++}$ so that two free and normal atoms are obtained.

*Possibility of a single electron transition.*—In the transition of a single electron from $X^{--}$ to $M^{++}$, the resulting compound is $M^+ X^-$ in the process $M^{++}X^{--} + h\nu = M^+X^-$. The electrostatic attraction is still present. A transition $M^{++}X^{--} M^+ X^-$ should give bands but these were not obtained in the present work. It is quite possible that the short absorption column used in the present work was not effective in showing the bands in absorption. They might be present in the extreme infra-red or ultra-violet regions which will be investigated later on. The absence of the fundamental bands in emission of Mecke, Mahanti and others in the present absorptions shows that these bands do not correspond to transition to the fundamental level, but between two higher levels.

My sincerest thanks are due to Professor M. N. Saha, D.Sc., F R.S , for valuable guidance and encouragement in connection with this work.

## SUMMARY

1. The Monoxides of the Alkaline Earth Metals absorb light continuously from a long wavelength limit.

2. From thermochemical calculations according to Born Cycle it is postulated that the long wave limit of absorption corresponds to the energy required to dissociate the molecule into its constituent atoms in their normal states.

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# CHEMICAL EXAMINATION OF THE BARK OF *NERIUM ODORUM*, SOLAND

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*Nerium Odorum*, Soland (N. O. Apocyanaceae) commonly known as Oleander in English, Kaner in Hindi and Karavi in Bengali and Sanskrit, is an ornamental garden plant cultivated throughout northern India. It is a well known poisonous plant of long use in Indian medicine. It has corked roots and thick and soft bark. The freshly cut bark exudes a pale yellow latex which on standing becomes resinous and sticky. It has long, slender, pointed leaves with red or white flowers. In the present investigation, the bark of the red variety was used.

As regards medicinal properties, both the root and the bark are highly useful. A decoction of the root is administered in a variety of fevers and the ground substance with water is applied in the form of a poultice on ulcers and boils. The bark is considered to be a powerful repellant and several preparations are made to be applied externally. It has been known for a long time that the active principle of *Nerium odorum* is a strong heart poison, producing powerful depression of the heart, and it is on this account that Prof. Pelikan suggested its use as a substitute for digitalis which is a well known heart depressant.

The bark of *Nerium odorum* was first examined by Greenish[1] and subsequently by Pieszezek[2] and Leulier.[3] They extracted from the bark a yellow aliphatic oil and a wax-like crystalline compound by petroleum ether, and two solid, bitter glucosides by alcohol. Greenish named the two glucosides as neriodorin and neriodorein. The authors did not go beyond studying the solubility of the compounds with different solvents and only the melting point of one of them is given as " above 56°". On the whole the statements of various authors regarding the active principle of the bark are very conflicting and no definite conclusion can be drawn from their work.

The present investigation was, therefore, undertaken with a view to subject the bark to a systematic chemical examination and determine its active constituents. As the result of that investigation it has now been

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shown by actual isolation that the bark contains small quantities of a volatile essential oil, a yellow fixed oil, two amorphous glucosides, a solid crystalline wax, a phlobaphene, a tannin and a dark red colouring matter. The presence in the fresh bark of traces of peroxidase and a hydrolytic enzyme has also been shown.

## EXPERIMENTAL

The dried and powdered bark was extracted with Prollius fluid and the extract tested with alkaloid reagents. A negative reaction indicated the absence of alkaloids. On ignition it left 13'5% of a white ash containing 78'0% of water soluble and 22'0% of water insoluble inorganic constituents. The soluble portion contained chlorides and sulphates of sodium and potassium together with traces of iron and the insoluble portion contained oxides of iron, aluminum and calcium together with comparatively large proportion of silica.

*Test for enzymes.*—The fresh bark on examination in the usual manner showed the presence of traces of a peroxidase (quinhydrone and purpurogallein reaction) and a hydrolytic enzyme (inversion of cane sugar). The absence of oxidase or reductase was also confirmed. In dried bark the enzymes become destroyed.

For complete analysis, 2 kilos of the dried and powdered bark were extracted with rectified spirit. The extract on cooling deposited a white flocculant precipitate which was filtered off (35 grams). The filtrate on concentration to a small volume under reduced pressure and allowing to stand deposited a sticky greenish yellow syrup from which the mother liquor was decanted off. The alcoholic mother liquor was then allowed to stand for a month pending the examination of other products.

*Examination of the white solid.*—The substance was thoroughly washed with chloroform and rectified spirit and then crystallised from boiling absolute alcohol in aggregates of colourless glistening prisms melting at 97°. The substance is sparingly soluble in cold alcohol, benzene, ether, chloroform, carbontetrachloride and petroleum ether, but dissolves to a moderate extent in hot alcohol, ethylacetate, acetone and pyridine. Concentrated sulphuric acid dissolves it with a yellow colour which slowly darkens and chars on warming. The substance was found to be a wax [Found: $C = 69'78$, $69'84$; $H = 11'40$, $11'52\%$. M. W. (Cryoscopic in benzene) $= 461,473$.] The wax had a sp. gr. of '9804, $(d^{30°})$ saponification value of $53'34$, iodine value of $16'2$, acid value of 16 8, and unsaponifiable matter of $62'4$. The acid obtained from it by hydrolysis with alcoholic potash in the usual manner crystallised from alcohol in plates melting at 93-94°. This melting point agrees with that of cocceric acid, m. p. 92-93°. The alcohol obtained from the wax after hydrolysis by extraction with ether, was recrystallised from absolute alcohol in

flattened prisms melting at 69°. From the melting point as well as other pro-
perties the substance appears to be carnaubyl alcohol, m. p. 68-70°. Hence the
wax obtained from the bark of the *Nerium odorum* appears to be the carnaubyl
ester of cocceric acid.

*Examination of the greenish yellow syrup.*—This was submitted to steam
distillation and the distillate extracted with ether. The extract on evaporation
of the ether left a small quantity of an essential oil which had the characteristic
odour of the drug. The quantity obtained, however, was too insufficient for
any systematic examination.

The residue after steam distillation was extracted with petroleum ether
and from the extract on complete evaporation of the solvent a yellow fixed
oil was obtained which had properties similar to olive oil, but this was also
too insufficient in quantity for systematic examination.

*Examination of the alcoholic mother liquor.*—The alcoholic mother liquor
on being allowed to stand for about a month deposited a little more of the
wax which was filtered. To the filtrate water was gradually added with
stirring, when a brown resinous substance was precipitated. The precipitate
was filtered off (20 gms.), washed thoroughly and dried.

The dark red filtrate was treated with aqueous lead acetate which
caused the immediate precipitation of a yellowish grey substance. The lead
compound was filtered off, washed with water and decomposed in aqueous
suspension with hydrogen sulphide. After the removal of the lead sulphide
the filtrate was evaporated to dryness. The substance thus obtained was an
astringent, amorphous brown powder which answered most of the properties
of tannins. Thus it dissolves in alkalies with a yellow colour and in concen-
trated sulphuric acid with a deep red colour. Ferric chloride gives a blue-
black colour and precipitate. Lead acetate gives a light yellow, gelatine
solution, a colourless and tartar-emetic, a light grey precipitate. The substance
shrinks at 210° and melts with decomposition at 240°. It does not reduce
Fehling's solution and is very soluble in water, alcohol, acetone and pyridine,
sparingly soluble in ethylacetate and completely insoluble in ether, benzene,
and light petroleum. (Found: C=54·6, 54·42; H=6·78, 6·73; Pb in the lead
salt=32·4, 32·8 %.)

The filtrate after the removal of the lead compound described above,
gave another precipitate with basic lead acetate. This second lead salt on
decomposition with hydrogen sulphide, removal of the lead sulphide and
complete evaporation of the mother liquor gave a dark red amorphous
powder which was found to have properties similar to tannin colouring
matters. Thus it dissolved in alkalies with a dark yellow colour from which
the original compound was precipitated unchanged on treatment with acid.
Concentrated sulphuric acid dissolves the substance with a dark brown colour
and the solution chars on heating. It does not reduce Fehling's solution. Its

general properties and solubility are allied to the substance described above. (Found: C, 53·2, 53·44; H, 5·7, 5·5%.)

*Examination of the mother liquor from the above.*—The mother liquor from the above substance was treated with hydrogen sulphide and after the removal of lead as sulphide, the filtrate was evaporated when a large amount of crystalline matter was obtained. This was found to be entirely inorganic. The mother liquor from this contained only reducing sugars.

*Examination of the brown resin described before.*—The substance was freed from oily impurities by extraction with petroleum ether and was treated in alcoholic solution with alcoholic lead acetate. The voluminous precipitate thus obtained was washed with boiling alcohol and was decomposed in alcoholic suspension with hydrogen sulphide. The filtrate on evaporation gave a dark brown amorphous powder melting at 120-122° and having a slightly astringent taste and characteristic smell of the drug. It is soluble in alkalies with a yellow colour from which it is reprecipitated with acids. It is soluble in alcohol, acetone and pyridine, sparingly soluble in acetic acid, ethyl acetate and water and insoluble in benzene, chloroform, carbontetra-chloride and petroleum ether. It gives a green coloration and precipitate with alcoholic ferric chloride. From the reactions it appears to be a phlobaphene. (Found: C, 57·9, 57·53; H, 7·16, 6·73%; Pb in the lead salt 36·16, 36·3 %.)

The mother liquor from the above lead acetate precipitate was treated with hydrogen sulphide to remove the excess of lead and after removal of the lead sulphide, the alcoholic filtrate was evaporated, when a bright yellow amorphous powder was obtained melting at 74° and having an extremely bitter taste. This was separated into two portions by ethyl acetate, one being soluble in the solvent and the other insoluble. The ethyl acetate soluble portion was apparently the *Neriodorin* obtained by Greenish. It is a bright yellow amorphous powder melting at 86-87° and having an extremely bitter taste. Concentrated sulphuric acid dissolves this substance with a bright red colour and nitric acid with a yellow colour. It is very soluble in alcohol, acetone, acetic acid and pyridine, moderately in ethyl acetate and insoluble in water, benzene, chloroform and ether. It does not reduce Fehling's solution except on hydrolysis. It is slightly laevo rotatory, $(\alpha)_D^{30°} = -1·04$. [Found: C=65·28, 64·94; H=7·43, 7·69 %; M. W.—ebullioscopic in acetone—390, 394, 388. $C_{22}H_{32}O_7$ requires C=64·7, H=7.8 %, and M. W.=408.]

The hydrolysis of neriodorin was carried out by moderately strong hydrochloric acid under reflux in alcoholic solution. The aglucone thus obtained was a yellow amorphous powder melting at 68°, and was altogether tasteless. The sugar obtained by hydrolysis was identified to be glucose by means of the osazone.

The ethylacetate insoluble portion of the resin described above was purified by repeated precipitation from alcoholic solution and was obtained

as a bright yellow amorphous powder melting at 106-107°. This substance has been named *Neriodorein* according to Greenish. It dissolves in concentrated sulphuric acid with a brownish violet colour and in nitric acid with an orange colour. Its general properties and solubility are practically very similar to the compound described above, *i.e.*, to neriodorin. [Found : C=56·4, 56·57; H=7·3, 7·17 % ; M. W.—ebullioscopic in methyl alcohol—483, 499, 494. $C_{23}H_{34}O_{11}$ requires C=56·79 ; H= 7·02 % and M. W.=486.]

The hydrolysis of neriodorein was carried on in the same way as in the case of neriodorin. The aglucone on repeated purification from alcohol was obtained as a yellowish white amorphous powder, melting at 70°. The substance is absolutely tasteless. The sugar was identified to be glucose.

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DIAGRAMMATIC REPRESENTATION OF THE ANALYSIS OF THE ALCOHOLIC EXTRACT FROM THE BARK OF *NERIUM ODORUM*

Hot Alcoholic Extract

Concentrated to 300 c.c.

Solid *Wax* separated on cooling; M. P. 97°C. (1·6%)

Chlorophyll and other Waxy material separated out

Steam distilled

Distillate—Pt. Ether extract on evaporation to dryness—*a few drops of essential Oil.*

Residue extracted with Pt. Ether and evaporated to dryness—*Very small quantity of Waxy material and a few drops of fixed Oil.*

Distilled water added.

Filtrate (*Water Soluble Portion*) Aqueous solution of lead acetate added.

*Resinous brown mass* (*Water Insoluble portion*) Redissolved in alcohol and alcoholic solution of lead acetate added.

Pb. salt (1) Decomposed by $H_2S$ in water suspension and the product isolated. *Amorphous Tannin* M. P. 240°C. (2%).

Filtrate, excess of lead removed by $H_2S$. Basic lead acetate solution added.

Lead salt (3) Decomposed by $H_2S$ in alcoholic suspension and the product isolated. *Brown amorphous Phlobaphene.* M. P. 120-22°C. (35%)

Filtrate, excess of lead removed by $H_2S$ and evaporated to dryness. *Bright yellow amorphous powder* Extracted with Ethyl acetate.

Basic lead salt (2) Decomposed by $H_2S$ in water suspension and the product isolated. *Deep red amorphous colouring matter* does not melt up to 250°C.

Mother liquor, excess of Lead removed by $H_2S$ as above and concentrated.

Residue, purified and the product isolated. *Neriodorein* (6%) M. P. 106-107°C.

Ethyl acetate extract, evaporated to dryness and the product isolated (5%) M.P. 86-87°C.

Inorganic Salts crystallised out.

Sticky, Syrupy mass, mostly reducing sugars.

# CYTOPLASMIC INCLUSIONS IN THE OOGENESIS OF PASSER DOMESTICUS

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## INTRODUCTION

Oogenesis of various kinds of animals occupies a distinctly significant place in the rank of current cytomorphic literature. The selection of bird as a type rests on its suitability as a material for investigation and the ease with which it can be obtained.

Sparrows were collected in the suburbs of Allahabad from October 1932 to February 1933 and the fixatives employed were those of Da Fano, Cajal, Ludford, Regaud, Regaud-Tupa, Zenker-Helly, F. W. A., Champy Kolatschev, Champy-Nassanov, and Bouin. Neutral red was prepared as directed by Bhattacharya in Bolles Lees' Vade mecum. This piece of research was carried on in the Zoological Laboratory, Allahabad University, under Prof. Bhattacharya to whom my cordial thanks are due for his constant guidance and help. The historical part has been omitted in this paper. It is exhaustively dealt with in the papers by Brambell (1925) and Das (1932).

## Observation

### Golgi Apparatus

In the youngest oocyte that can be obtained the Golgi apparatus appears in the form of a few discrete spherical granules seen prominently against the crystalline background of the cytoplasm (Fig. 1). At this stage the nucleus occupies the larger portion of the cell and the cytoplasm is of a uniform consistency with the few grains of the Golgi complex occupying a juxtanuclear area on the side farthest from the periphery. With the growth of the cell there occurs a definite reduction in the relative size of the nucleus, while the cytoplasm shows a corresponding increase in bulk. The Golgi bodies grow much larger in number and embrace the nucleus from all sides, thus exhibiting a decided tendency towards a perinuclear condition (Fig. 2). Ultimately the Golgi bodies completely encircle the nucleus though the greater

portion of the main mass remains confined to the original area (Fig. 3). The cytoplasm, however, fails to maintain its uniform consistency, the juxtanuclear cytoplasmic seat of the Golgi apparatus (D'Hollander's Yolk Nucleus of Balbiani) being obviously of a much denser texture than the rest of the cytoplasm (Figs. 4 and 5). In the middle of this restricted area appears a clear space lodging two small granules (Fig. 4). The small dark grains scattered over the dense juxtanuclear cytoplasmic area (not shown in Fig. 4) are identified as the Golgi bodies while the clear space carrying the two granules as the centrosome lodging the diploid centrioles. This mass, later on, begins to break up in a peculiar fashion. The Golgi elements of the interior either completely disintegrate and disappear or migrate towards the periphery of the mass. The result of the process is the formation of a capsular structure with a clear central space and a sort of wall built up of Golgi bodies (Figs. 3 and 5). The clear cytoplasm of the interior is much denser and corresponds to the 'archoplasm' of other writers. This stage is of a short duration and does not always intervene as a definite step in the morphological changes the Golgi apparatus undergoes. When it does occur it is sometimes followed by a re-accumulation and further growth of the Golgi bodies. The mass ultimately breaks up and the Golgi bodies disperse through the cytoplasm till they are evenly distributed throughout. Later on, due to their outward migration, a cortical concentrated band of Golgi bodies becomes established. And this band persists even after the elements of the interior have disintegrated and become ultramicroscopic. Ultimately this band also disappears and no Golgi elements can be detected anywhere in the cell. The Golgi bodies are generally in the form of solid spherical grains and do not show the chromophilic and chromophobic parts.

*Mitochondria*

Like Golgi apparatus, mitochondria also occur as a few discrete granules very close to the nuclear membrane at one pole in a young oocyte (Fig. 7). With the growth of the cell they increase in number but remain confined to this pole with the result that a concentrated mitochondrial mass gets formed on this side of the nucleus (Figs. 8 and 10). The granules are scattered over a dense cytoplasmic stratum which stands out in sharp relief against the background of the nearly clear cytoplasm (Fig. 9). Obviously this is 'archoplasm' as mentioned previously. The mitochondrial mass gets later transformed into a transitory capsular structure (Fig. 10) appearing almost as a counter-part of the similarly-shaped structure mentioned in connection with the Golgi apparatus. The mass ultimately disintegrates and the elements undergo rapid dispersal till they are evenly distributed over the entire cytoplasm. This is followed by a cortical concentration of the mitochondria brought about by the outward migration of the granules of the interior. Still later three distinct concentrated

bands of mitochondria become established—one perinuclear, the second middle and the third cortical (Fig. 11). The granules in the intervening regions are few and are drifting away. The granules become very fine but could be detected even in the biggest egg the writer could examine. The mitochondria are in the form of granules and rods, the granules being the more common.

### Egg Membranes

The earliest oocytes are almost naked the only covering being a poorly preserved extremely thin membrane (Fig. 1). There is no sign of any follicle cell as yet and no trace of any fibrous sheath. Very shortly, however, some cells can be perceived lying irregularly around the oocyte and later, by rapid multiplication, they form one continuous covering for the egg. Between the follicular layer and the periphery of the egg there is no intervening membrane of any description. Outside the follicular layer there is a fibrous sheath of connective tissue. In the early stages this band does not show any differentiation into sharply divided layers (Fig. 13) but during the later stages of oogenesis and especially at the time when the follicular epithelium becomes many-layered a differentiation is detected in the staining capacity of the thecae. The internal layer or the theca interna stains more intensely than the theca externa. The cells of the thecae are elongated and their nuclei have a similar shape. Their cytoplasmic inclusions—Golgi bodies and mitochondria—are fine granules. The Golgi bodies of the follicular epithelium occupy a position between the nucleus and the cell wall next to the periphery of the oocyte. At this stage the epithelium is a single-layered band completely enclosing the egg and no zona radiata has yet been formed. It is at this stage that the "infiltration" of the Golgi bodies occurs (Fig. 5). The Golgi elements lying at the periphery of the cell in the figures 3 & 5 have been transported from the follicular cells and do not belong to the egg proper. The infiltering elements are in the form of spherical granules and not solid lumps.

Figure 6 represents a much later stage. Two definite layers of fibrous sheath—theca externa and theca interna—have become established. Zona radiata, though not outstandingly prominent, is a more or less distinct structure. The Golgi bodies are uniformly scattered but the follicular epithelium is still single-layered. The Golgi apparatus of the follicle cells is a patch of fine grains situated in a juxtanuclear position, facing towards the egg proper. And these fine grains are filtering down into the oocyte. Just beneath the zona radiata lying in the periphery of the egg is a band of Golgi bodies.

The single-layered condition of the follicular epithelium persists only for a brief interval. The cells undergo rapid multiplication and with the increase in the size of the egg proper grow considerable in number. The epithelium

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becomes double-layered (Fig. 11) and eventually may become multi-layered. It is generally at this stage that the zona radiata is fully formed and is distinctly perceptible.    During the formation of the additional layers of the follicular cells a process of differentiation sets in. Some of the cells stain much more deeply than the others and in between the normal lightly staining cells are also found non-cellular patches which have taken a deep homogeneous stain (Fig. 8). These exhibit apparently the extreme condition to which the dark cells are reduced. The lighter cells possess the normal cytoplasmic inclusions (Golgi bodies and mitochondria). Not so the dark cells. They do not appear to possess these inclusions and have fallen into a state of decay and degeneration. The nuclei of the cells contain a number of deeply staining nucleoli. They colour deep red with acid fuchsin and intense blue with haematoxyline.

The zona radiata does not show any structure and no follicular prolongation into the substance of the zona radiata could be made out. It does not exhibit any evidence of a differentiation into two well marked layers and persists as a single, homogeneous non-striated band.

The mitochondria do not infilter at any stage of the oogenesis, and are present in the follicle cells as fine grains. Like Golgi bodies they occupy the juxtanuclear position facing the egg periphery.

In close proximity to the thecae occur numerous luteal cells presenting a glandular appearance.

The follicle cells sometimes show abnormal activity. They multiply rapidly and invade the cytoplasm of the egg and eat away, as it were, the entire egg.

*Yolk-bodies*

An examination of the osmic-treated material clearly shows that only one kind of yolk is present—the fatty yolk. There is absolutely no trace of any albuminous yolk. In osmic-fixed preparation these bodies appear dense black and not pale-yellowish as is often, though not always, the case with albuminous yolk, and a short immersion in acid-free turpentine decolourizes them. They are never fixed by the current non-osmic fixatives and are extremely unstable. Even the xylol of Canada balsam dissolves them out in the mounted sections (Fig. 5). Staining with Sudan III gave the confirmatory reaction of fat and they got coloured with neutral red if left in that vital dye for a sufficiently long period, say 90 to 100 minutes. They never stain with acid fuchsin.

The centrifuge experiment throws them to the upper pole, these being the lightest inclusions. The centrifuge experiment also clearly demonstrates the absence of albuminous yolk. The empty vacuoles arranged on the cortex in non-osmic preparations are fatty yolk vacuoles which were not

preserved by the fixatives and were washed out in the subsequent process (Fig. 6).

The fatty yolk bodies arise in the juxtanuclear area and also on the cortex. It is usual to find them arranged on the periphery but in many cases they fill the interior as well.

The fatty yolk does not arise independently in the ground cytoplasm but in intimate association with the Golgi bodies which are mainly responsible for their formation. All gradations between the minute particles of the Golgi bodies and the swollen spheres of yolk are present (Fig. 12). The periphery is crowded with big and small spheres of fatty yolk with the Golgi bodies scattered in between them. Besides, on treating the sections with acid-free turpentine or immersing the slide for a long time in xylol yolk dissolves out but black crescents and granules are left bordering the empty vacuoles. (Fig. 13).

With the growth of the oocyte the fatty yolk bodies increase enormously in number and also swell up to attain greater dimensions. There is, however, distinctly perceptible a stage beyond which the fatty yolk bodies tend to become distinctly smaller though concomitantly more numerous.

An abundance of fatty material is found to be filling very young oocytes in certain cases. This fat is much more unstable than the ordinary Golgi yolk and in fixed preparations the cells containing them present a highly vacuolated appearance. The archoplasm stands out in strong contrast in such cells. This appears to be a case of fatty degeneration and not a normal process.

*Intravitam*

Examination of thin strands of ovary in salt solution under strong artificial light (1000 candle power) did not show the Golgi bodies. The younger cells were comparatively free from yolk globules and the cytoplasm appeared a clear crystalline expanse containing a few refringent granules. In very young oocytes a dense juxtanuclear area corresponding to the "Yolk Nucleus of Balbiani" could be picked out. The older cells were densely packed with fatty yolk spheres.

Treatment of fine pieces of ovary with neutral red brought out Parat's vacuome. In early cells these red granules were confined to the "Yolk Nucleus of Balbiani" area but in more advanced ones they were scattered throughout the cytoplasm (Fig. 14). These minute red granules were generally scattered individually but were also found in groups (Fig. 14). Occasionally some of them ran into each other to form a single big structure

(Fig. 14). The "Vacuome" of the follicle cells are likewise in the form of fine red granules scattered throughout the follicle cells. It takes nearly an hour before the vacuome are distinctly seen, though half an hour may suffice in some cases. After the vacuome have clearly come out a little quantity of 1% osmic acid is run into from one side and drained from the other. The Golgi bodies come out as homogeneous grains and crescents. In the advanced oocytes they are homogeneously distributed (Fig. 14) but in young eggs they are confined to the juxtanuclear area. The Golgi bodies of the follicular epithelial cells are minute particles mostly gathered in a patch near the nucleus.

A simultaneous application of neutral red and janus green B met a failure. Pieces of ovary separately treated with janus green B showed mitochondrial patches with remarkable clearness. Mitochondria were in the form of rods and granules situated in a patch on a denser substratum of cytoplasm. These patches were regularly arranged concentrically round the nucleus (Fig. 15) and the arrangement continued in sufficiently advanced oocytes.

The mitochondria of the follicular cells were invariably found in the form of a prominent juxtanuclear patch facing the periphery of the egg.

Fatty yolk spherules get blackened on prolonged treatment of the tissue with osmic acid. But for the confirmation of the presence of fat Sudan III test is more satisfactory. It was used on fresh and formalin-treated material and in both cases showed the usual red reaction.

## Discussion

### Golgi Apparatus

By a majority of prominent cytologists the Golgi body is treated as a permanent structure independent of any canalicular or vacuolar apparatus and possessing a fundamental chemical and structural basis in spite of the diversity of form and function it may assume in different varieties of cells. It is credited with the power of growth, assimilation, and fission and is considered a cytoplasmic inclusion of universal occurrence. It is not considered a product of metabolism.

Still there is no undisturbed unanimity. Walker and Allen (1924) openly condemned Golgi apparatus as an artefact produced by the action of fixatives on the cytoplasmic colloids. Benseley and Helen (1929) showed that osmication involves no chemical reaction but is simply a process of reduction, dispersal and adsorption. Strangeways and Canti (1927) did not find Golgi bodies in their dark ground experiment on tissue culture cells. Chambers (1931) in the course of his micro-dissection found no area of resistance in the cell.

The Golgi apparatus has, however, been seen intravitam. Gatenby easily observed them in male germ cells of Cavia and Abraxas, by applying neutral red  Gatenby, Rau, and Brambell were able to produce microphotographs of the Golgi bodies of living male germ cells. Bhattacharya and Das (1929) demonstrated it by travitam methods in the oocytes of pigeon. Nath saw the apparatus intravitam in the eggs of earthworm and frog. Das (1932) observed it in the living unstained oocytes of pigeon.

The observation of the present writer is in conformity with those of the latter group. The Golgi apparatus is easily seen on treating the fresh ovary with 1% osmic acid for a short time and though the method is not strictly intravitam, it does not involve any danger of artefact. (Strangeways and Canti 1927.)

The morphology of the Golgi apparatus admits of extensive variation. Cajal considered it a system of canals with a limiting membrane enclosing lipoids. Hirschler (1913, 1914, 1916, 1918) advanced the theory that the Golgi apparatus is of a duplex character and essentially lamellar in construction. An existent representative of Hirschler "Apparatinhalt" was found by Bowen in the chromophobe of the apparatus. Kunze 1921, Brambell 1923, Brambell and Gatenby 1923 showed that in the nerve cells of Helix the Golgi body consists of curved rods or ring-shaped dictyosome. Harvey showed it to be scaly in form but Nath in a series of papers on oogenesis declared that the only form of the apparatus is vesicular with chromophilic cortex and chromophobic interiors. Bhattacharya described many forms in the tortoise,—rodlets, platelets, crescents, beaded strings, etc. (1925).

In the material under investigation the Golgi bodies were mostly in the forms of spherules, rods and crescents. It does not, however, seem necessary to reduce the morphology of the Golgi apparatus to a standard form.

The functional significance of the apparatus in oocyte remains obscure. In many cases it has been shown to form fatty yolk. But beyond this little more is known  In male germ cells it forms the "acrosomes" (Bowen, Gatenby and others) and in glands it is held responsible for the formation of the secretory material. Its function thus varies with the nature of the cell in which it is lodged. In female germ cells its only function known so far is to supply nutriment to the developing ovum  In the eggs of Passer domesticus the Golgi apparatus is concerned with the same function.

### Mitochondria

Mitochondria have been seen intravitam in the eggs of a number of animals by workers in this laboratory. The dark ground experiments of tissue culture conducted by Strangeways and Canti (1927) conclusively showed their presence in living tissues and Chamber's report (1931) is equally

confirmatory. In the present work mitochondria were seen by intravitam methods very clearly.

In the eggs mitochondria are generally present in the form of granules and rods. In a few cases the filamentous forms have also been described; (Hibbard in Discoglossus, Hibbard and Parat in Pygostens and Perca, Harvey in Lumbricus, King in Peripatus, Bulliard in Emy lutaria, Gatenby in Apanteles and Bhattacharya and collaborators in a number of animals from our laboratory).

The present writer finds only granular and rod-like mitochondria in the eggs of Passer domesticus.

Very early oocytes of the material under investigation were entirely free from mitochondria. Gardiner in Limulus and Harvey in Carcinus met a similar failure and a number of workers from this laboratory have reported similar cases. The continuation of mitochondria from the undifferentiated germ cells to the segmenting ovum is, however, a well-established belief among the cytologists and there is a wealth of evidence to support it. It is possible that at very early stages they are in ultra-microscopic condition and hence escape detection.

Mitochondria play absolutely no part in the process of vitellogenesis of the oocytes of Passer. This is in sharp disagreement with the reports of Brambell on the oogenesis of domestic fowl and of Das on pigeon who ascribe the formation of proteid yolk to mitochondria.

Van Durme's account of mitochondria contains a description of three zones into which the mitochondria get concentrated during the early stages of dispersal. These three zones are prominently seen in the eggs of sparrow but they never give rise to proteid yolk. Brambell does not record these layers and Das mentions only an ultimate cortical concentration. This cortical band is an intermediate stage in the oogenesis of Passer domesticus.

### Egg-Membranes

The mature egg of this bird is enveloped by theca externa, theca interna, follicular epithelium and zona radiata. I have not met the cortical fibrillated layer situated between the periphery of the cell and the zona pellucida as mentioned severally by Gatenby and Bhattacharya. And the zona radiata is a single and not a permanently double-layered structure. Das (1932) thinks this fibrillated layer to be the vacuolated part of the cortex. There is no such vacuolated area in the cortex of the oocytes of the Passer, the only vacuoles being those of the fatty yolk. What Gatenby and Bhattacharya described as fibrillated layer is probably a separate structure not found in birds.

The zona radiata has been described as marked by definite radiations and traversed by hollow strands of cytoplasmic material of the follicle cell in fishes, reptiles, mammals and birds (Loyez, Van-der Stricht, Champy, Thing,

etc.). The zona radiata of Passer is unstriated and does not show any prolongation of follicular substance.

Hall, Brambell, Mertens and Das described two kinds of cells in the follicular epithelium of the oocytes of birds and fishes—clear and dark cells. My observation is in agreement with those of these workers. The differentiation of the dark cells from the light normal cells is brought about by a process essentially degenerative in character, the non-cellular dark patches being the extreme stage. These dark patches seldom or never extend across the full breadth of the follicular layer and there is little reason to ascribe a mechanical function to these, as Brambell has done. Further, it is significant to note that nearly all the follicular cells in cases of abnormal activity are like dark cells—dark and devoid of the usual cellular inclusions.

The nutrition of the oocyte demands an inflow of nourishing substance through the enveloping layers and the actual occurrence of such a process has been known for long (Loyez 1905, Waldayer 1870). The nature of granules filtering down into the cytoplasm of the egg has been only recently investigated (Bhattacharya and Brambell). The infiltration in the oogenesis of this bird occurs both before and after the formation of the zona radiata. Das (1932) came to a similar conclusion, but Brambell has recorded only one stage. The significance of the intrusion of the Golgi bodies becomes apparent on the assumption of their nutritive function.

## Vitellogenesis

For a bird the absence of albuminous yolk is rather an exceptional fact. Van Durme (1914), Brambell (1925) and Das (1932) all found it and traced its formation to the mitochondria. Mitochondria have been held responsible for albuminous yolk formation by various other workers in different animals (Hirschler, Bhattacharya, Nath, Lams and Doorme, and Bhattacharya and collaborators from this laboratory). Nucleolar extrusions have been ascribed the same function in many cases (Gatenby, Nath, King, Gresson and others).

Weiner, Harvey and Steopoe derived albuminous yolk from Golgi bodies, while Nath, Parat and Hibbard and Parat declared " vacuome " to be the source in some cases. It is difficult to accept the former interpretation as of late the Golgi apparatus is being considered the main source of fatty yolk formation (Gatenby, Ludford, Brambell, Nath, King, Bhattacharya, Das and others). The observation of the present writer is in agreement with the interpretations of the latter group.

## Vacuome

Parat's vacuome hypothesis considers the classical Golgi apparatus an artefact created by metallic precipitation in and around a system of neutral red-stainable vacuoles which are the real pre-existent organelles of the cell.

Benseley first described a canalicular apparatus in the cell and Guilliermond and Mangenot later emphasized the canalicular nature of the Golgi apparatus in plant cells. Guilliermond extended the hypothesis to animal cells. But a complete vacuolar hypothesis was put forth by Parat and Painleve (1924).

Parat contended that under the influence of cytological fixatives the vacuoles get disorganised, run and coalesce together to form the typical Golgi network. His work centred mainly round secretory materials. Krjukowa (1929), Beams and Goldsmith (1930) repeated Parat's work on salivary gland cells of chironomus larva and reported that they did find the typical crescentic Golgi bodies which Parat had overlooked.

Parat, however, had to explain the dictyosomes stuck over the archoplasm in many germ cells (Gatenby, Bowen, etc.) Parat called them "*chondriome actiff*" or modified mitochondria while the vacuoles they enclosed were termed the "vacuome." Avel, Gatenby, Bowen, Pollister and others definitely rejected this view. This "Lepidosome" theory never attracted any enthusiastic support.

Parat's vacuome theory was supported by workers on protozoon Cytology (Joyet and Lavergne, Hall, Hirschler, Volkonsky, Lwoff and Lwoff, Cowdry and Scott and many others). Covel and Scott as a result of their neutral red experiments on spinal Ganglion cells came to the same conclusion. Beams (1931) emphatically contradicted this and showed that the interpretation of Covel and Scott was erroneous.

Neutral red itself does not seem to be a very specific dye. Vera Koehring (1929) coloured several system of Protozoa with it which cannot be homologized with Parat's vacuome. Then the work of Chlopin (1927, 1928), Weiner ('30) shows that the neutral red, though the least toxic vital stain, is responsible for creating artefacts and thus causes misinterpretation. In his latest paper on chironomus larva salivary gland cells Gatenby showed that neutral red created artificial spaces that were mistaken for pre-existent structures (Vacuome) and that the independently occurring Golgi bodies were real but separate bodies.

Moreover, the Golgi apparatus and vacuome have been seen simultaneously by many workers (Tretjakoff, Grabowski, Rumjantzew, Beams, Beams and King, Bhattacharya and Das, and Nath). The separate roll of the two structures in spermatogenesis was worked out by Voinova, Payne, Pollister, Hirschler, Monne and Gatenby.

In the oocytes of Passer domesticus the two structures are completely independent and have been simultaneously demonstrated. There is no reason to suppose the vacuome to be a secretory product of the Golgi body and at the same time it is difficult to treat "Vacuome" as a mere artefact. They cannot be brought out in dead cells and did not collapse on subsequent osmication.

*Nucleolar Extrusion*

There is no sign of nucleolar extrusion in this animal.

## SUMMARY

In the oogenesis of Passer domesticus

1.  The Golgi bodies appear in the form of a few granules in young oocytes, grow in number, form the "Yolk-Nucleus of Balbiani" with a clear central space, spread out, and get arranged on the cortex in a concentrated band.  They ultimately disappear.

2.  Centrosomes and centrioles have been demonstrated in the Yolk Nucleus of Balbiani area.

3.  Golgi bodies give rise to fatty yolk.

4.  Mitochondria appear in early oocytes as a few granules which increase in number, form Yolk Nucleus of Balbiani, then spread out and form three concentrated layers

5.  There is no albuminous yolk.

6.  Vacuome and Golgi bodies have been shown to be independent structures and are shown intravitam.

7.  Mitochondria have been demonstrated by intravitam methods.

8   There is no sign of nucleolar extrusions.

## EXPLANATION OF LETTERING

| | | | | | |
|---|---|---|---|---|---|
| G. B. | ... | Golgi Bodies. | Mi. P. | ... | Mitochondrial Patch. |
| Mi. | ... | Mitochondria. | Va. | ... | Vacuome. |
| Y.N.B. | ... | Yolk Nucleus of Balbiani. | G. Gr. | ... | Golgi granules. |
| F.G.B. | ... | follicular Golgi bodies. | G. Cr. | ... | Golgi crescents. |
| F.C | ... | Follicle Cells. | F.Y.B. | ... | Fatty Yolk body. |
| F.N. | .. | Follicular Nucleus. | C.S. | ... | Central space. |
| F. Nu. | ... | Follicular Nucleolus. | | | |
| N. | ... | (Oocyte) Nucleus. | B.V. | ... | Blood Vessel. |
| L.M.C. | ... | Layer of Mitochondrial Concentration. | F.V. | ... | Fatty vacuoles. |
| Inf. | ... | Infiltration. | V. | ... | vacuoles. |
| Th. in. | ... | theca interna. | L.C | ... | Light Cell. |
| Th. ex. | ... | theca externa. | D.C. | ... | Dark Cell. |
| Z.R. | ... | Zona Radiata. | N.C.P. | ... | Non-cellular Patch. |

## EXPLANATION OF PLATES

Fig.  1.  Early oocyte showing a few juxtanuclear Golgi granules.  Da Fano. toned.

Fig.  2.  More advanced oocyte.  Golgi bodies have grown in number and are spreading on sides Da Fano. toned.

F. 8

Fig. 3. Golgi bodies have surrounded the nucleus. Yolk Nucleus of Balbiani with a clear central space. Infiltered Golgi bodies are on the periphery. Da Fano toned.

Fig. 4. Yolk Nucleus of Balbiani with centrosomes lodging centrioles. Da Fano toned and stained with Iron-alum haematoxyline.

Fig. 5. Yolk Nucleus of Balbiani with the central space. Golgi bodies are spreading out and fatty vacuoles are present. Infiltered Golgi bodies are on the periphery. Ludford bleached.

Fig. 6. Infiltration of Golgi bodies. Zona radiata is forming and thecae are two-layered (Cajal).

Fig. 7. Young oocyte showing a few mitochondrial granules. F.W.A. Acid Fuchsin.

Fig. 8. Yolk Nucleus of Balbiani. F. W. A. Acid Fuchsin.

Fig. 9. More advanced oocyte. Mitochondria are present in two patches and are spreading out. F.W.A. Acid Fuchsin.

Fig. 10. Microphotograph of an advanced oocyte showing a juxtanuclear patch of mitochondria with the central space. F W. A. Iron-alum Haematoxyline.

Fig. 11. Mature oocyte. Mitochondria are arranged in three concentrated layers. Zona radiata is formed; dark cells and non-cellular patches are formed. Follicular epithelium is two-layered. Thecae have differentiated into two layers.

Fig. 12. Part of an old oocyte showing the formation of fatty yolk bodies. Theca externa, theca interna, and blood vessels are shown. (Ludford.)

Fig. 13. Showing Golgi bodies left after dissolving out fat. (Ludford.)

Fig. 14. Part of an old oocyte showing vacuomes and Golgi bodies. Neutral red and Osmic.

Fig. 15. A young oocyte showing concentric mitochondrial patches. Janus Green B.

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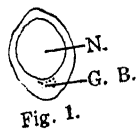
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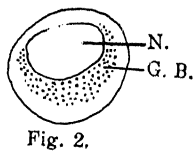
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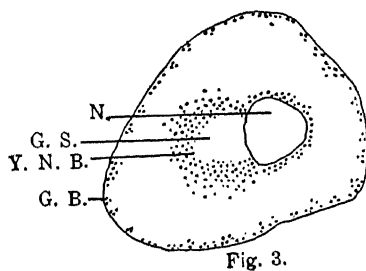
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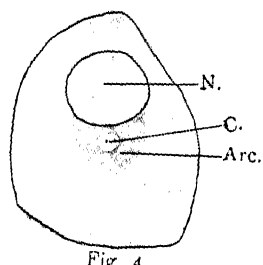
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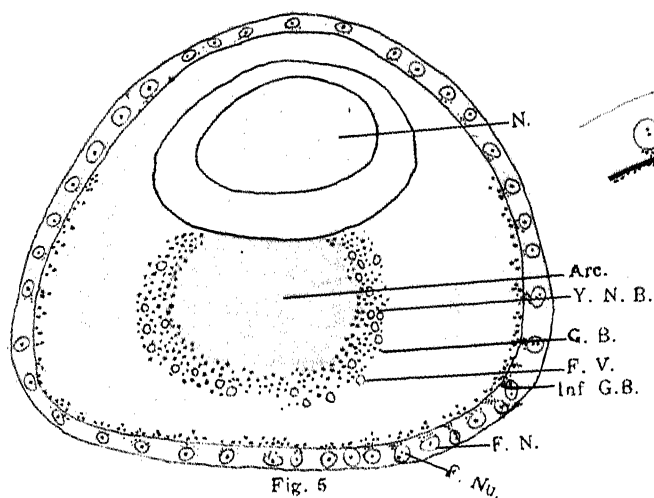
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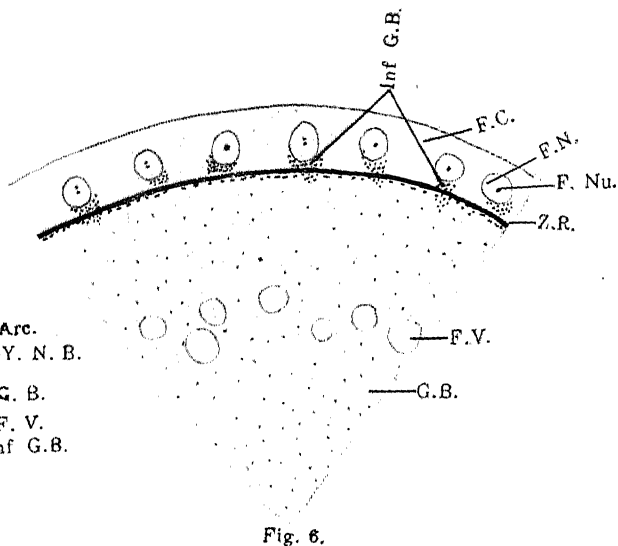
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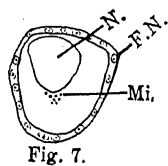
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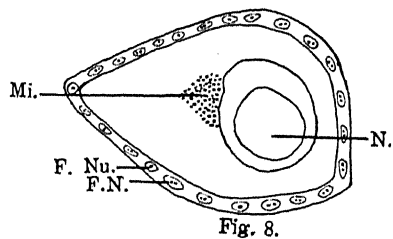
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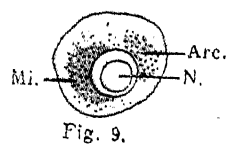
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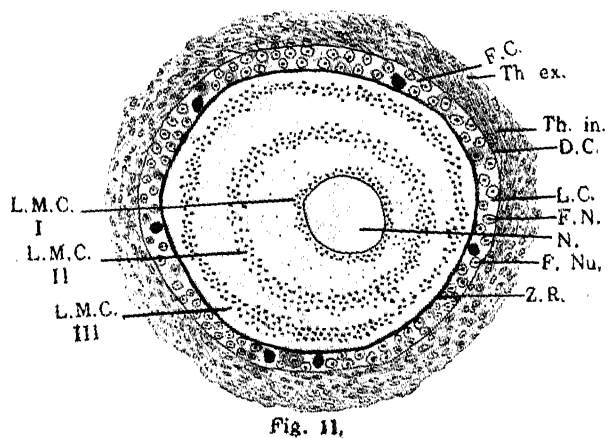
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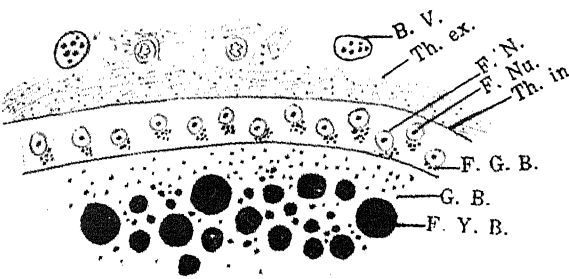
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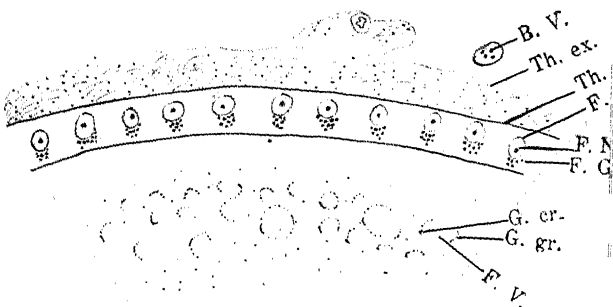
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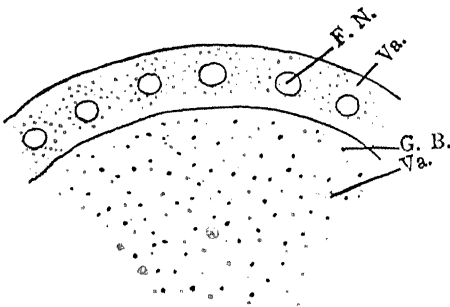
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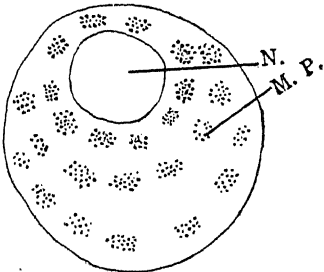
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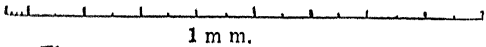
1 m m.
Fig. 1,2,3,4,5,6,7,8,12,13,14,15.
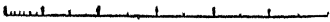
5 m m.
Fig. 9,11.

# ON THE ABSORPTION SPECTRA OF THE HALIDES OF ELEMENTS OF THE FIFTH GROUP

By HRISHIKESHA TRIVEDI.

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This paper is an extension of my previous work[1] on the absorption spectra of some of the lower chlorides of the elements of this group. The substance investigated are the bromides and iodides. I have also examined antimony penta-chloride to see if there was any correspondence between the results obtained in the case of antimony trichloride previously examined and those obtained here.

As was said in the previous paper[1] these salts can be regarded as saturated compounds. As an illustration we may consider $PI_3$. Its constitution may be given by $P^{+3}$ $3\bar{I}$ . Each $I^-$ —ion is diamagnetic and $P^{+3}$ has the constitution $1s^2$ $2s^2$ $2p^6$ $3s^2$; hence $P^{+3}$ is also diamagnetic. The case of bromide is similar and the same is the case with the halides of other elements of this group. All these substances should show continuous absorption.

Their atomic heats of formation are calculated as in the previous paper. They are calculated by the help of the following formula which is based on the Born cycle. In the case trihalides the atomic heat of formation in kcals is

$$R = Q + L_M + \tfrac{3}{2} D_{Ha_2} - L_{MHa_3}$$

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where Q = heat of formation of the salt in kcals per mole.

$L_M$ = heat of vaporisation of the metal from the condensed state to the atomic state in kcals per mole.

$D_{Ha_2}$ = heat of dissociation of the halogen (Ha) in kcals per mole.

$L_{MHa_3}$ = heat of vaporisation of the salt in kcals per mole.

$L_M$ is in its turn calculated by the help of relation

$$L_M = \frac{L + D_1 + 2D_2}{4}$$

where L = heat of vaporisation of the metal from the condensed state to a vapour of tetra-atomic molecules.

$D_1$ = heat of dissociation of a tetra-atomic molecule into diatomic ones in kcals per mole.

$D_2$ = heat of dissociation of the diatomic molecule into monatomic ones.

As an example we take the case of As $I_3$. Here Q = 28·8 kcals; S = 26·5 kcals; $\frac{3}{2} D_{I_2}$ = 53·4 kcals and $L_{AsI_3}$ = 19·2 kcals; whence we get the value for R to be equal to 89 5 kcals.

All the necessary data have been taken from Landolt and Bornstein's tables and from Mellor's Treatise on Inorganic and Physical Chemistry. In the case of certain compounds, however, the value for latent heat of vaporisation of the compounds is not given as such. In that case we obtain this value from the data for vapour pressures of the substance at various temperatures. The formula employed for getting this result is

$$L \text{ in cals.} = \frac{T_1 T_2}{T_2 - T_1} \log_e P_2/P_1$$

where the pressures $P_1$ and $P_2$ correspond to temperatures $T_1$ and $T_2$ respectively given in absolute scale.


EXPERIMENTAL PROCEDURE AND RESULTS

The experimental procedure was similar to that described in my previous paper.[1] In certain cases the absorption began in the quartz region, whilst in others it began in the glass region. In the former case the source of radiation was a hydrogen tube run by a transformer with a current density of 100 mA. The spectrograph was a quartz one of $E_3$ type. The plates used were process plates. In the other case the source of radiation was a pointolite lamp, the spectrograph was a glass one of the constant deviation type and the plates were Agfa panchromatic.

In the case of antimony pentachloride the substance was a liquid and it was kept in a side bulb which was maintained at the temperature of boiling

water. According to tables the saturated vapour pressure at this temperature is 63 mms of mercury, while the pressure recorded in the manometer attached to the tube is 60 mms. The absorption tube was then heated successively to the temperatures mentioned in the horizontal row of table 2. Micro-photographs of these plates were taken at the laboratory of the Muslim University, Aligarh, by Dr. Asundi and the beginning of the long wavelength limit of absorption could be easily inferred from these re-cords. It was found that at the lower temperatures, the rise of the absorption curve was gradual and became more so when the temperature was increased. The long wavelength limit was found to be continuously shifting from the value $\lambda$ 3500Å at 100°C. to $\lambda$ 4100Å at 340°C. The experiment, therefore, shows that the long wavelength limit shifts with the temperature. To see if there was any retransmission, the furnace was kept at room temperature and the pressure of the vapour in the absorbing column was varied from 1 mm. to 76 cms. of mercury by gradual steps. It was found that there was no retrans-mission.

The other substances were solids. For the sake of convenience, a little of solid was placed in each case inside the absorption vessel and heated to the temperatures mentioned in the top row of table No. 2. Both the pressure and the temperature of the absorbing column were thereby varied. The long wavelength limit was determined in the same way as before. Generally at lower temperatures, the absorption curve was found to be gradual and it became sharp as the temperature was raised. For SbBr$_3$ the effect was more marked.

All these substances were examined to see if there were retransmission in any of them. For that purpose the temperatures to which they were heated was varied from the room temperature to a maximum of 340°C. by very gra-dual steps. This ensured that the pressure of the absorbing column was changed from very low values to higher ones very gradually.

In all these cases with the exception of AsI$_3$ and SbBr$_3$, no other change except the shift in the long wavelength limit of absorption could be noticed with the changes in the conditions of temperature and pressure. The long wavelength shift was, in each case, towards the red end of the spectrum.

In the case of AsI$_3$ and SbBr$_3$ there was, in each of them, a retransmis-sion of light following a continuous absorption which in its turn terminated in another continuous absorption. Thus there were two long wavelength absorp-tion limits in these two cases corresponding to the two continuous absorp-tions separated from one another by the small patch of retransmission. The retransmissions appear at a comparatively high temperature, which shows that a comparatively large pressure of the absorbing column is required to make those retransmissions appear. These results are given in table 3. It was found that as the temperature increased the retransmitted patch

contracted from both sides. A similar phenomenon was observed in the case of tinhalides.[4]

The microphotograms of the various absorption spectra are given in figures 1 to 6. For economy of space all the microphotograms for one substance taken under various conditions are compressed in one figure. The microphotograms have been taken along the spectra. The microphotogram is (A) of the continuous spectrum from the hydrogen tube, (B) of the continuous spectrum from the pointolite lamp, (1) the absorption spectrum of the vapour of the substance at 50°C, (2) the absorption spectrum at 100°C., (3) the absorption spectrum at 300°C., and (6) the absorption spectrum at 340°C.

### Table 1

| Substance | Long wavelength limit in Å "$v_m$" | $Q_m = \dfrac{Nh v_m}{J}$ in kcals | Heat of reaction required to convert solid element into monatomic vapour in kcals "$L_M$" per gm. atom | Heat of formation of the salt in kcals per mole "Q" | Heat of dissociation of the halogen molecule into atoms in kcals per mole "D" | Heat of vaporisation of the salt in kcals per mole "L" | $\dfrac{R}{3}$ in kcals for trihalides and $\dfrac{R}{5}$ in kcals for pentahalides | $Q_m - \left[\dfrac{R}{3} \text{ or } \dfrac{R}{5}\right]$ in kcals |
|---|---|---|---|---|---|---|---|---|
| Antimony pentachloride | 4130 | 68·9 | [27·6] | 104·8 | 56·87 | 11·05 | 52·7 | 16·2 |
| Arsenic tribromide | 3248 | 87·6 | 26·5 | 59·1 | 45·22 | [10] | [47] | 47·6 |
| Antimony tribromide | 5450 | 52·2 | [27·6] | 76·9 | 45·22 | 3·5 | 56·2 | —4·0 |
| Phosphorus triiodide | 3147 | 87·4 | 34·5 | 26·7 | 35·6 | [12] | [34] | 53·4 |
| Arsenic triiodide | 5616 | 50·6 | 26·5 | 28·8 | 35·6 | 19·2 | 29·8 | 20·8 |

*N. B.*—1. The values enclosed in brackets are uncertain because of the interpolation referred to in my previous paper.

2. $v_m$ corresponds to that long wavelength limit of absorption which is nearest to the red in those cases where there are more than one absorption limits.
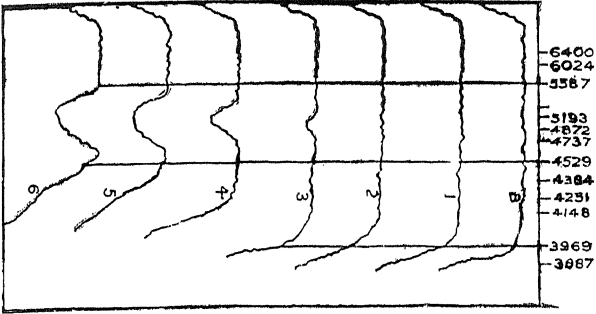
Fig. 1
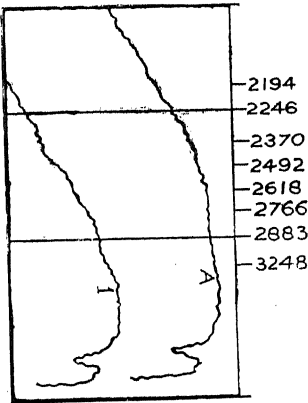
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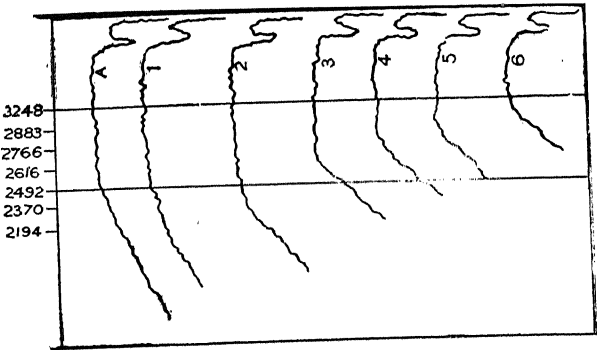
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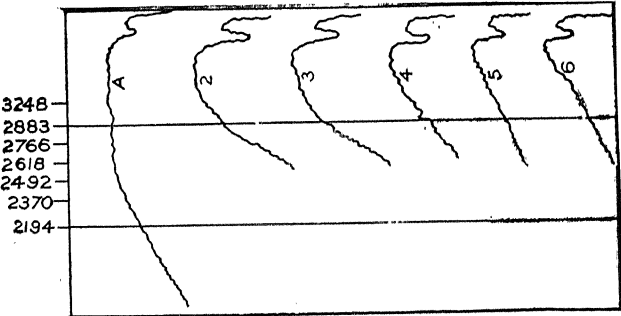
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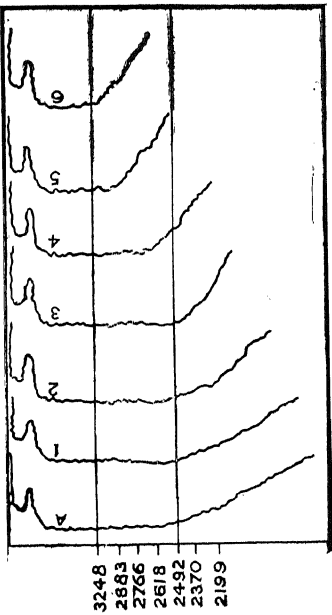
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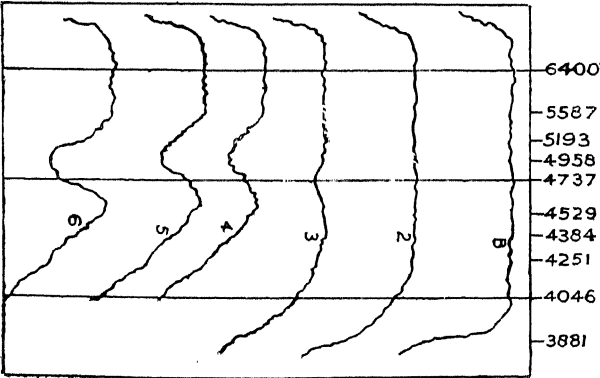
Fig. 6

## EXPLANATION OF THE PLATE.

The microphotograms are marked as follows :—

A—The microphotogram of the continuous spectrum from the hydrogen tube.

B—The microphotogram of the continuous spectrum from the pointolite lamp.

1—The absorption spectrum of the vapour of the substance at 50°C.

2—The absorption spectrum of the vapour at 100°C.

3—The absorption spectrum of the vapour at 180°C.

4—The absorption spectrum of the vapour at 250°C.

5—The absorption spectrum of the vapour at 300°C.

6—The absorption spectrum of the vapour at 340°C.

The various figures give the microphotograms of the following substances :—

Fig. 1.   Arsenic tri-iodide.

Fig. 2.   Antimony tri-bromide.

Fig. 3.   Phosphorus tri-iodide.

Fig. 4.   Arsenic pentachloride.

Fig. 5.   Antimony tri-bromide.

Fig. 6.   Arsenic tri-bromide.

*Table 2*

*Long wavelength limit of absorption of the vapours of the various substances at different temperatures in Angstrom units.*

| Temperature in °C  Substance | 50 | 100 | 180 | 250 | 300 | 340 |
|---|---|---|---|---|---|---|
| Antimony pentachloride | ... | 3500 | 3670 | 3820 | 3965 | 4100 |
| Arsenic tribromide    ... | 2100 | 2390 | 2595 | 2815 | 3020 | 3240 |
| Antimony tribromide   .. | 3200 | 4110 | 4920 | 5444 | 5443 | 5450 |
| Phosphorus triiodide   ... | 2095 | 2280 | 2485 | 2700 | 2920 | 3120 |
| Arsenic triiodide     ... | 4002 | 4100 | 5070 | 5300 | 5465 | 5600 |

*Table 3*

| Substance | First long wavelength limit of absorption "$\nu_{m_1}$" | | Second long wavelength limit of absorption "$\nu_{m_2}$" | | $\nu m_2 - \nu m_1$ cms.$^{-1}$ | Difference between the energies of the first two metastable states of the corresponding halogen $(2P_{\frac{1}{2}} - 2P_{\frac{3}{2}})$ cms$^{-1}$. |
|---|---|---|---|---|---|---|
| | Å | cms.$^{-1}$ | Å | cms$^{-1}$ | | |
| Antimony tri-bromide | 52·60 | 19011 | 4670 | 21413 | 2402 | 7600 |
| Arsenic tri-iodide | 5440 | 18349 | 4600 | 21739 | 3390 | 3700 |

DISCUSSION

Saha and Datta's hypothesis[2] says that the long wavelength limit of the absorption spectrum of the vapour of a substance which can be represented by $MX_n$ is given by $\frac{R}{n}$ where R is its atomic heat of formation. We find, however, that the energy of optical dissociation is in each case different from one-third of the thermochemical value in the case of trihalides and one-fifth for pentahalides. As found in the chlorides[1] of this group the value is in excess to the thermochemical one. But this excess is not general. In the case of

F. 9

antimony tribromide, for instance, the energy of optical dissociation is 52·2 kcals, whereas one-third of the thermochemical energy is 56·2 kcals. The thermochemical value is, however, not quite reliable. Its calculation involved the use of the value of the heat of vaporisation of antimony from the condensed state into monatomic vapour. This was obtained only by interpolation, on which much reliance cannot be placed. This deviation from the general behaviour may, therefore, be only fortuitous.

In the cases of $AsBr_3$ and $PI_3$ the atomic heats of formation (R) are $(153·4-L_{AsBr_3})$ and $(114·6-L_{PI_3})$ kcals respectively. The melting points of $AsCl_3$, $AsBr_3$ and $AsI_3$ are $-13°C$., $31°C$. and $146°C$. respectively and the heats of vaporisation of $AsCl_3$ and $AsI_3$ are 6·7 and 19·2 kcals respectively. From this it can be seen that the latent heat of sublimation of $AsBr_3$ will be approximately 10 kcals and $\dfrac{R}{3}$ will, therefore, be approximately equal to 47 kcals.

Similarly, the value of $\dfrac{R}{3}$ in the case of $PI_3$ is approximately equal to 34 kcals    The values of the energy of optical dissociation of these salts are equal to 87·6 and 87·4 kcals respectively. The difference between the optical and thermochemical values is very large. In the case of $AsBr_3$ the optical value roughly equals $\frac{2}{3}R$. If this equalisation be considered and Saha and Datta's hypothesis[2] be taken to be true, we should consider it to be a case in which two bromine atoms have been knocked off simultaneously by the incoming radiation. This explanation appears to be improbable because the dislodging of one bromine atom from $AsBr_3$, whose probability is greater and which should manifest itself by another absorption did not take place. In the case of $PI_3$ things were just the same. Here the value of the energy of optical dissociation was a good deal more than $\frac{2}{3}R$ and as in the previous case no other absorption could be traced. This anomaly cannot, therefore, be attributed to the knocking off simultaneously of two halogen atoms from the molecule by the incident radiation.

It was found, in addition, that there are some compounds for which the long wavelength limit of absorption varies as we increase the temperature of the substance by fairly wide degrees. There are others for which the variation is very little. In the case of $SbBr_3$, for instance, after the substance had been heated to $250°$ C. the long wavelength limit of absorption does not further shift towards the red with greater increase in its temperature. In the case of others the shift towards the red takes place regularly as the temperature goes on increasing. The shifts are not alike in all the cases. In the case of $SbCl_5$ and $AsI_3$, for example, the shifts are large at lower temperatures, but go on reducing as the temperature increases. In the cases of $AsBr_3$ and $PI_3$ they are equally large all over.

It is to be noted that in the case of SbBr$_3$, where there is no shift above about 250°C., the values of the energy of optical dissociation and of $\frac{R}{}$ are nearly equal. In the case of SbCl$_5$ and AsI$_3$, where the shifts go on reducing with the increase in temperature, the difference between the energy of optical dissociation and $\frac{R}{n}$ is small, as compared to $\frac{R}{n}$. In the case of AsBr$_3$ and PI$_3$, where the shifts remain the same all over the range of temperature, the difference between the two values is large as compared to the values of $\frac{R}{3}$.

These facts are very significant. Unfortunately, in these compounds heating brings about both a change in the temperature of the gas and a change in the pressure of the absorbing column. Experiments with hydrogen halides are being conducted where this ambiguity between the temperature and pressure effect could be eliminated at will. They can still be explained as follows. The transition from the stable electronic level to a higher unstable one takes place in the three cases as represented by Franck Condon diagrams[3] in the figures (*a*), (*b*) and (*c*).

In case (*a*) the upper level is disposed as shown in the figure. When the transition takes place from the lowest vibrational level of the stable electronic state it goes up to the higher state at a point where it is not horizontal. With the increase in the vibrational level in the lower state, brought about by an increase in temperature, there is both a horizontal and a vertical shift in the position of the point of maximum transition probability on the lower curve. The vibrational energy
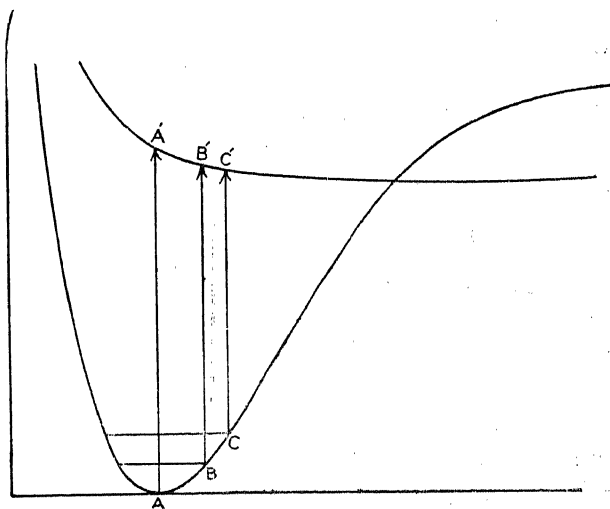


Fig. (*a*)

being small and the curve itself being not very much steep there, the vertical shift is very small as compared to the horizontal one. But with a horizontal shift in the position of maximum transition probability in the lower curve, the vertical distance as represented by the arrow get considerably reduced because of the slope of the curve. This vertical distance represents the energy of the beginning of absorption. This slope of the upper curve goes on reducing as we

go further to the right. Therefore on a further horizontal shift in the position of maximum transition probability brought about by an increase in the temperature of the substance we go to points having smaller slope on the upper curve and the vertical distance represented by arrows does not change so much. On the upper curve such points with a small slope are only very slightly above the horizontal line asymptotic to it. Since the height of this asymptote above the lowest vibration level of the lower state gives the heat of dissociation of the salt the value obtained optically is only very slightly greater than the heat of dissociation or it may be equal to or even a little less than the thermochemical value.
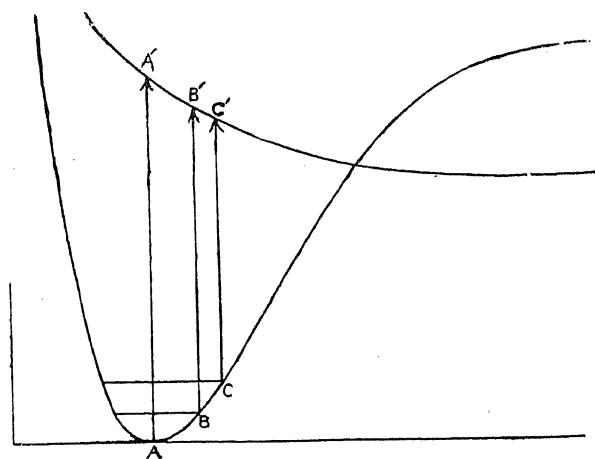


Fig. (b)

In case (b) the upper curve has got a greater slope at all the points to which the transition takes place at various temperatures used in the experiment. The horizontal asymptote is in this case below the most extreme right of these points. The heat of dissociation obtained optically is, therefore, greater than $\dfrac{R}{3}$.

The case (c) is much more extreme. Here at the points to which the transition takes place the upper curve has a far greater slope and the asymptote will be very much below these points. The value of energy of dissociation obtained optically is, therefore, much greater than $\dfrac{R}{3}$.
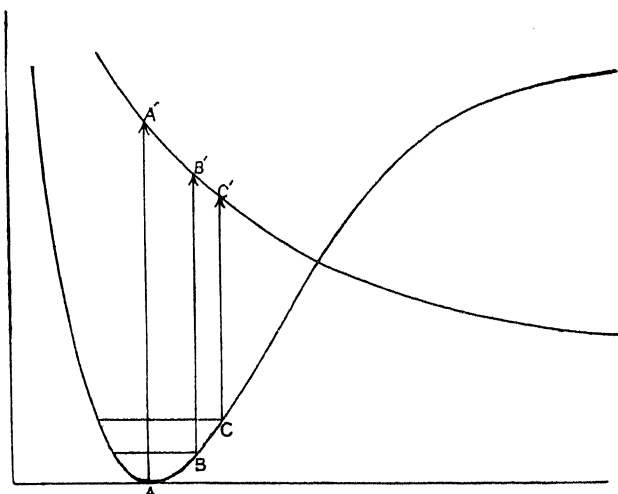


Fig. (c)

These observations enable us to review the validity of Saha and Datta's hypothesis.[2] We see that in the case of compound $SbBr_3$ where the upper Franck Condon curve is practically horizontal at the point of transition and

therefore the long wavelength limit of absorption gives the true value of the energy of optical dissociation, Saha and Datta's hypothesis[2] is found to be valid. In the case of other compounds the limit of absorption does not give the true value of the energy of optical dissociation, for the upper curve has a much larger slope at the point of transition. The greater the deviation of the limit of absorption from the energy of optical dissociation, the more is Saha and Datta's hypothesis found to be invalid. It might be, therefore, very much possible that Saha and Datta's hypothesis is true and, in the very many reports which we have been having regarding its alleged invalidity, the error might have been made in computing the energy of optical dissociation from the long wavelength limit of absorption by disregarding the effect of the slope of the upper curve at the point of transition.

Coming to the third feature of these results it is found that although the salts examined are bromides and iodides, retransmission is to be found only in the case of $AsI_3$ and $SbBr_3$. These appear only at rather high temperatures as found in the case of tinhalides.[4] The difference between the energies of an iodine atom in $^2P_{3/2}$ and $^2P_{1/2}$ states is 7600 cms.$^{-1}$, whereas the difference

between these limits in the case of $As I_3$ is only 2402 cms$^{-1}$. It is obvious, therefore, that this difference is not due to the breaking off of the iodine atom in its two metastable states. As we have seen in the case of tindichloride[5] the retransmissions can also be due to the breaking off of the molecule into residual molecules in different metastable states. The two absorptions are, therefore, probably, due to $AsI_3$ breaking up into iodine and $AsI_2$ (normal and excited). In the case of $SbBr_3$, the corresponding difference is 3390 cms$^{-1}$. The difference between the energies of the normal and excited bromine atoms is 3700 cms$^{-1}$. The two retransmissions may represent the breaking off from the molecule of a normal and an excited bromine atom in the two cases. But the discrepancy between the two differences warns us not to place much reliance on this explanation. The possible explanation should again be sought in the dissociation of the molecule into Br and two dibromides of arsenic (normal and excited). It is curious that in all such polyatomic molecules retransmissions corresponding to the two metastable levels of bromine and iodine are conspicuous by their absence. An explanation of this is, however, still wanting.

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# ON NEW TREMATODES OF FROGS AND FISHES OF THE UNITED PROVINCES, INDIA.

**Part III.**—On a new Genus Mehraorchis and two new Species of Pleurogenes (Pleurogenetinæ) with a systematic Discussion and Revision of the Family Lecithodendriidæ.

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## Mehraorchis ranarum.    Nov.. gen., nov spec.

Host—*Rana cyanophlyctis*
Habitat—The body cavity, usually the pancreatic region.
Locality—Sitapur, Oudh (India)

These interesting distomes are found enclosed in cysts in the body-cavity of—*Rana cyanophlyctis*—a fairly common frog in the ponds of Sitapur district. The cysts, each containing 2—5 parasites, are usually found in the pancreatic region of the host. The maximum frequency of infection is about 40 per cent and the number of parasites varies from 2—14 in a single host. The non-transparent and sluggish-looking worms are of a dirty brown colour with little power of contraction and expansion. The thick ovoid and slightly convex body is beset with straight bluntly-pointed short spines, 0·013 mm. long and 0·005 mm. thick at the base. The spines at the anterior end are thickly crowded but in the post-acetabular region they are smaller in number and far separated from one another. The spines do not project out of the surface of the body. Sexually mature parasites when alive measure 2·4—4·1 mm. in length and 1·3—2·8 mm. in maximum breadth which occurs in the region a little behind the acetabulum. In fixed specimens the dimensions vary from 2·6—4·1 mm. in length and 1·4—2·9 mm in breadth. The size of the parasites depends largely upon the number enclosed in a cyst. Usually the cysts contain only two parasites which are bigger in size than those in cysts containing a larger number. The suckers are poorly developed and have a spherical outline. The subterminal and ventrally directed oral sucker is 1·2—1·3 times as large as the acetabulum which lies at the junction of the anterior and the middle thirds of the body. A prepharynx is absent. The

muscular pharynx is conical measuring 0'176 mm. in length with an equally broad base. At times it may protrude slightly into the cavity of the oral sucker. A circular constriction divides the lumen of the pharynx into a shorter anterior and a larger posterior chamber. Posteriorly it leads into a fairly long œsophagus, 0'38 —0'56 mm. in length and 0'08—0'12 mm. in breadth, which bifurcates at the end of the anterior one-fourth body length. The two wide intestinal cæca extend up to the broad posterior end of the body. Large amœboid cells line the lumen of the wide intestinal cæca; their nuclei being situated basely and the distal projecting pseudopodia appear largely vacuolated.

The testes are massive and have a roughly triangular or rhomboidal shape usually with an irregular margin. They are situated right and left in the region bounded on each side by the œsophagus, the intestinal cæcum and the body-wall. The right testis, 0'56—0'76×0'32—0'54 mm. in dimension, is placed a little in advance of the left which is pushed posteriad by the presence of a well-developed cirrus sac situated in front on the same side. The left testis is usually a little smaller than the right and measures from 0'42—0'8 mm. in length and 0'27—0'43 mm. in maximum breadth. The vas efferens of the right testis crosses in front of the ventral sucker to the left side and runs forwards till it unites with the small vas efferens of the left testis to form a rather inconspicuous vas deferens which enters the large and coiled vesicula seminalis. The latter is an inverted U-shaped structure, with a constriction in the middle, occupying the posterior two-fifths of the cirrus sac. The cirrus sac, measuring 0'48—0'6 ×0'12—0'24 mm., is a well-developed, broad, bluntly-pointed, spindle-shaped structure with its extremities slightly curved in opposite directions. It lies obliquely anterior to the left testis extending behind and lying ventrally up to the commencement of the left intestinal cæcum. The vesicula seminalis passes anteriorly through a small narrow duct into an elongated conical pars prostatica measuring 0'2—0'3 ×0'05—0'01 mm. Throughout its length the pars prostatica is surrounded by numerous prostate gland cells with prominent rounded nuclei. The anterior curved and narrow part of the cirrus sac encloses a fairly long ductus ejaculatorius which opens into the genital atrium ventrally to the vaginal pore. The small knob-like cirrus is not covered with spines.

A massive ovary of variable shape usually with a markedly crenated outline lies partly overlapping the ventral sucker in the space between the latter and the right intestinal cæcum. It measures from 0'26—0'5 mm. in length and 0'26 to 0'45 mm in breadth. A small elongated bulb-shaped receptaculum seminis is situated to the left side of the ventral sucker. The Laurer's canal arises from the neck of the receptaculum semi iis just before it opens into the oviduct. The oviduct dilates to form the ootype where it is surrounded by a diffuse mass of shell gland cells. The common vitelline

duct forms a small triangular yolk reservoir which opens into the oviduct immediately before it passes into the ootype. The uterus first runs parallel to the receptaculum seminis and then continues downwards in a more or less straight course in the median line almost parallel to the length of the body This descending portion of the uterus is filled with ·sperms and is to be rega.ded as receptaculum seminis uterinum. The ascending part of the uterus lies in convoluted transverse windings which posteriorly do not extend behind the bifurcation of the excretory bladder; and anteriorly beyond the ovary and the vitellaria. Laterally, however, they extend outside the intestinal cæca reaching almost the body margins. In one specimen in my collection the uterine coils ·are seen extending as far as the extreme hinder end but this condition is probably due to too much pressure to which the specimen was subjected during fixation. The uterine coils are mostly confined to the ventral half of the body. In its terminal portion the uterus runs straight in an oblique direction from the ventral sucker to join a feebly muscular metraterm which opens into the shallow genital atrium. The vaginal pore is seen lying dorsal to the male genital opening on the left body margin in a slight depression—"the genital atrium." The whole uterus is packed with innumerable eggs of a deep brown colour. The eggs are operculate and measure $0.03 - 0.33 \times 0.013 - 0.015$ mm. The easily eversible shallow genital atrium lies in level with the pharynx.

The vitellaria of the two sides lie laterally confined to the ventral surface of the body underneath the testes and the intestinal cæca, extending slightly inward towards the median line but not meeting each other. The right vitelline gland lies a little anterior to that of the left side, extending from the middle of the œsophagus to a little distance behind the posterior margin of the acetabulum. Inwardly also it spreads further towards the median line partly covering the ovary. The left vitelline gland occupies the region from behind the obliquely placed cirrus sac to a short distance behind the ventral sucker. The vitellaria never extend backwards to overlap the uterine coils. Each gland consists of a number of closely scattered bunches of grapelike follicles. Small vitelline ducts arise from these groups and fuse to form one large duct on each side. The vitelline duct of each side runs towards the median line and unites with its fellow of the other side near the ventral sucker to form a yolk reservoir which, as mentioned before, opens into the oviduct through a small common vitelline duct.

The excretory bladder is somewhat Y-shaped with the stem of a smaller length than the cornua; its shape approaches somewhat midway between that of latters Y and V. The main stem bifurcates anteriorly at $0.32 - 0.48$ mm. from the posterior end. It measures $0.27 - 0.43$ mm. in length and has a funnel-shaped outline with the greatest breadth of $0.16$ mm. at its anterior margin. At its anterior corners arise the cornua, one on each side, extending

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as far forward as the ventral sucker. The terminal part of the main stem is surrounded by deeply staining parenchymatous cells which form a sphincter around the opening. The excretory opening lies subterminally at the posterior end on the ventral side of the body.

This interesting parasite is assigned to the subfamily *Pleurogenetinæ* Looss as defined by Mehra and Negi 1928, with which it presents unmistakable affinities on account of the topography of the genital organs and the position of the genital pore on the left body margin. The excretory bladder, though somewhat different, can, nevertheless, be derived from the typical V-shaped condition characteristic of the subfamily, by the union of the arms for some length forwards to form a moderately long main stem. Amongst the known genera of the *Pleurogenetinæ* it resembles *Pleurogenes* in the form of the body, the relatively great length of the intestinal cæca and its occurrence in cysts *(P. arcanus Klein* 1905 occurs encysted in the liver, pyloric region and neck of urinary bladder of frogs). It resembles somewhat the genus *Prosotocus* in the position of its testes which lie one on each side in the anterior part of the body, but the left testis, however, lies behind the cirrus sac and not in front of it as in *Prosotocus* The vitellaria are confined, as in the genus *Ganeo*, to the ventral half of the body. In all other important features this species does not fit in with any of the known genera, therefore, a new genus is created for its reception. The genus is named after Dr. H. R. Mehra to whom my respectful gratitude is due, for his invaluable help and advice.

*Generic Diagnosis* —Pleurogenetinæ, small, fleshy, ovoid with flattened elliptical cross section ; integument spiny, spines sparsely distributed in post-equatorial region. Suckers small, slightly muscular, acetabulum smaller than the oral sucker lying at the junction of anterior and middle thirds of body-length. Prepharynx absent ; pharynx well-developed and muscular ; oesophagus moderately long ; intestinal cæca extending nearly up to the posterior end. Testes massive ; asymmetrically situated in the anterior body to the right and left in the space between oesophagus, intestinal cæca and body-wall. Ovary to the right side, partly overlapping the ventral sucker. Vitellaria, confined to the ventral half in the anteriolateral region extending almost to the median line, composed of a large number of grape-like bunches. Laurer's canal and receptaculum seminis present ; shell gland diffuse, situated close to the acetabulum. Genital atrium shallow, easily eversible ; situated on a level with the pharynx on the left body margin ; male and female openings separate. Excretory bladder with a somewhat prominent stem and longer cornua ; excretory pore subterminal and ventral. Muscular cirrus sac situated obliquely, antieror to left testis ; containing well-developed coiled vesicula seminalis, pars prostatica and ductus ejaculatorius. Uterus post-ovarian, not extending behind blind ends of intestinal cæca ; metraterm present. Ova

numerous small, operculate, measuring 0˙03—0˙033×0˙013—0˙015 mm. in size.

Encysted in the body cavity, especially in the pancreatic region of Amphibia.

### Genus Pleurogenes, Looss, 1896

This is the oldest genus belonging to the subfamily *Pleurogenetinæ* Looss 1899, the type species of which was described by Rudolphi in 1819 as *Distoma clavigerum*, parasitic in the intestine of Anurans. V. Linstow in 1888 described the same parasite under the name *Dist. negletum*. Pagenstecher in 1857 and Pachinger in 1888 described with figures a distome similar to that described by Rudolphi and gave it the same name. Olsson described the specimens of *Dist. medians*, which he found in the intestine of Anurans in 1876. Sonsino also described the same form in 1894 as *Dist. tacapense*, which Looss in 1898 renamed as *Dist tacapensis*. Looss in his well-known paper published in 1899 pointed out the identity of *Dist. clavigerum* Rud. with *Dist. negletum*, V. Linstow and of *Dist. medians* Ols. with *Dist. tacapense* Sons and *Dist taca-pensis* Lss. The only representative of the genus *Pleurogenes*, parasitic in the Reptilia was described in 1896 independently by Looss and Sonsino, as *Dist. tacapense* from the intestine of *Chamaeleo basiliscus*. Two years later Looss gave this species its present name of *Pleurogenes tener* and in the following year transferred it to the genus *Prosotocus*. Stafford in 1905 follow-ing Looss retained it under *Prosotocus*, but Klein, in the same year, however, transferred it back to the genus *Pleurogenes*, adding two more new species to the genus, *i.e.. P. sphericus* from the intestine of an Indian frog *R hexada-ctyla* and *P. arcanus* found encysted in the liver, pyloric region and around the neck of the urinary bladder of some members of *Ranidae*. The latter species was first described by Stafford in 1900 as *Dist. medians* Ols. and almost at the same time by Nickerson as *Dist. arcanum*. Four years later Stafford created a new genus *Loxogenes* for *Dist. arcanum*. Mehra and Negi in 1928, following Klein, have referred it to the genus *Pleurogenes* in their key. Tubangui in 1928, Fuhrmann in 1928, Travassos in 1930 and Krull in 1933 have, however, retained the genus *Loxogenes*. As will be seen from the discussion the genus *Loxogenes* cannot be maintained. *P. gastroporus*, parasitic in the intestine of *R. cyano-phlyctis* India, was described by Luhe in 1901 and a new variety of it *var. equalis* from the intestine of *R. tigrina* was added by Mehra and Negi in 1928. Johnston in 1912 described *P. freycineti* and *P. solus* from the intestine of Australian tree frogs, *Hyla freycineti* and *H. aurea*. Travassos in 1921, following the suggestion made by Stafford in 1904 split up the genus *Pleurogenes* Lss. into two groups on the basis of the length of the intestinal cæca. Group one, comprising of the species with intestinal cæca extending beyond the ventral

sucker he retained as the genus *Pleurogenes*; whereas for the species in which the cæca are short, never extending beyond the centrum of the acetabulum, he created a new genus *Pleurogenoides*. Mehra and Negi in 1928 divided the genus *Pleurogenes* Lss. into two sub-genera—*Pleurogenes* and *Telogonella*—on the basis of the length of the intestinal cæca and the position of the genital pore. In the sub-genus *Pleurogenes* the intestinal cæca do not extend posteriorly beyond the centrum of the acetabulum and the genital pore is more cephalad, while in *Telogonella* the cæca extend posteriorly beyond the acetabulum and the genital pore is not so anteriorly situated. In his papers published in 1930 and 1931 Travassos reaffirms the validity of his genera *Pleurogenes* and *Pleurogenoides*. The study of intermediate species between the two genera created by Travassos, such as *P. orientalis* n sp, *P. lobatus* Ozaki 1926 and *P. intermedius* Isaitschikow 1926 (Travassos did not consult this paper) has convinced me of the untenability of the genus *Pleurogenoides* Trav., which I accordingly drop, referring all its species back to *Pleurogenes* Looss. Ozaki in 1926 described *P. lobatus* from the bile ducts of Japanese frogs—*Polypedates buergeri*. Two years later Tubangui found a specie *P. taylori* in the intestine of *R. vittigera* in Philippine. In 1930 Travassos described *P. stromi* from the intestine of *R. esculanta* and Africa *P. loossi* from the intestine of the same host. The latest addition to the list of species of this genus is *P. minus* parasitic in the intestine of Pike—*Esox lucius*, described by Pigulewsky in 1931. I add in this paper two new species to this genus from the gut of *R. cyanophlyctis* Northern India).

## Pleurogenes orientalis.—n. sp.

Host—*Rana cyanophlyctis*.
Habitat—Intestine.
Locality—Sitapur, Oudh (India).

In its frequency of occurrence this species is as rare as *Prosotocus infrequentum* Srivastava 1933. In August 1932 only two frogs were found infected with one parasite each, out of over a hundred specimens of *R. cyanophlyctis* examined The distomes show little power of contraction and expansion and are of a light brown colour. The thin and transparent body is ovoid in form with broadly rounded ends and is studded with minute backwardly directed spines except in the region behind the excretory opening. In balsam mounts the parasites measure 1·4—1·6 mm. in length and 0·96—1 1 mm. in maximum breadth across the acetabular region. The suckers are fairly large and muscular with spherical outline. The oral sucker, 0·27—0·28 mm. in diameter, is larger than the acetabulum and is situated on the ventral surface a little behind the anterior end. The acetabulum lies for the greater part of

its diameter in the posterior half of the body measuring 0'22 mm. in diameter The size ratio of the oral and the ventral suckers is 4 : 3.

The genital opening is situated on the left body margin in level with the junction of the anterior and middle thirds of the oral sucker. The excretory pore is subterminal, situated on the ventral surface a little in front of the hinder end. A muscular pharynx, 0'064×0'012 mm. in size, lies at the base of the oral sucker The œsophagus being entirely absent the pharynx is immediately followed by the intestinal bifurcation which lies 0'3 mm. in front of the acetabulum. The intestinal cæca at first run more or less horizontally, one on each side and then continue their downward course, laterally near the body-wall, terminating a little behind the acetabulum, just in front of the posterior third of body length.

The testes lie symmetrically near the lateral body-walls, one on each side, immediately behind the blind extremities of the intestinal cæca about the junction of the middle and posterior thirds of the body length. The right testis is nearly spherical in shape, measuring 0'19 mm. in diameter, while the left testis, 0'14×0 17 mm. in size, is more or less ovoid in outline. The vasa efferentia, which arise as delicate tubes from the anterior margin of each testis, run forwards separately for a short distance before they unite in the median line close in front of the acetabulum to form a small vas deferens which soon enters the cirrus sac. The cirrus sac is well developed and situated to the left side, ventrally to the left intestinal cæcum, extending from the anterior margin of the acetabulum to the level of about anterior one-third diameter of the oral sucker. It is quite large for the size of the distome, measuring 0'72 mm. in length, and consists of a basal horizontal club-shaped part and a narrow tubular vertical part The angle of curvature between these two parts is a sharp right angle. The basal club-shaped part encloses a coiled vesicula seminalis of 0'32 mm. length and a fairly long pars prostatica which becomes narrower towards its terminal end, where it passes into the ductus ejaculatorius of 0 3 mm. length. The cirrus sac opens terminally into the inconspicuous genital atrium which lies on the left body margin.

The ovary, 0'13 mm. in diameter, is spherical and is situated to the right side about the end of the first body-half, close inside and in contact with the right cæcum, at about the level of the anterior half of the acetabulum. The oviduct arises from the middle of its inner margin and is joined after a short length by a flask-shaped receptaculum seminis of 0'13 · 0 15 × 0'08 — 0'1 mm. size which lies obliquely to the right side of the acetabulum between it and the ovary. As in the other species of *Pleurogenetinæ* a small Laurer's canal arises from the receptaculum seminis. The yolk reservoir, the shell gland mass and the receptaculum seminis are all lodged in the space between the ovary and the acetabulum.

The vitellaria are well developed and confined to the anterior half of the body. The follicles are scattered mesially between the oral sucker and the acetabulum, running into one another at a few places, but they are much aggregated laterally extending from the middle of the oral sucker to the level of about the middle of the acetabulum.

The uterus arises from the right side of the acetabulum, passes downwards and forms in the post-acetabular region a compact convoluted mass filling a little more than the posterior one-third of the body. The ascending part of the uterus passes distally to the left side of the acetabulum, running parallel and outer to the cirrus sac, before it terminates into a feebly muscular metraterm. The metraterm opens in the inconspicuous genital atrium to the left side of the male opening. The uterus is packed with numerous small operculate eggs of a light brown colour measuring 0'023 × 0'013 mm. in size

The excretory bladder is V-shaped with its cornua extending anteriorly up to the posterior margin of the testes. The excretory pore lies on the ventral surface, 0 13 mm. distance in front of the posterior end of the body.

This interesting species differs remarkably in many features from all the other species of the genus *Pleurogenes* Lss. It resembles somewhat *P. gastroporus* and *P. gastroporus var. equalis* in the shape of its body, shape of the excretory bladder, position of the excretory pore and the uterine convolutions being confined to the post-acetabular region. But it differs from them in such important features as the relative position and size ratio of the suckers, absence of the œsophagus, relative length of the intestinal cæca, shape and disposition of the vitellaria, topography of the gonads, the shape and position of the cirrus sac and the position of the genital pore.

### Pleurogenes sitapurii.—n. sp.

Host—*Rana cyanophlyctis*.

Habitat—Duodenum.

Locality—Sitapur, Oudh (India).

The parasites belonging to this species are the smallest of all the distomes infecting *Rana cyanophlyctis*. They were first met with about the middle of July 1932. During the rainy season (July—September the frequency of infection is about 40 per cent varying in intensity from 6—25, but with the approach of winter it gradually declines. The parasites are usually found attached to the wall of the descending part of the duodenum. Only once they were found throughout the length of the duodenum. In their natural habitat they appear as minute dust particles, rendered conspicuous by the colour of the contained ova. They are so delicate that they can hardly bear the weight of even a small glass coverslip. They appear to be extremely susceptible to changes in diet and temperature, as they cannot live for more than an hour in any

nutritive solution. In the living condition they are grey in colour and show little power of contraction and expansion, measuring 0.78—0.94 mm in length and 0.46—0.64 mm. in maximum breadth which lies across the acetabulum. The body is comparatively thick and presents an oval outline, narrower anteriorly and broader and somewhat rounded off behind. In entire mounts the size varies from 0.6—0.96 mm. in length and 0.35—0.5 mm. in maximum breadth, according to the state of contraction. The cuticle is covered all over with fairly large and pointed spines of 0.013 mm. length.

The suckers are feebly muscular and have a circular outline. The oral sucker is subterminally situated on the ventral surface, measuring 0.11—0.13 mm. in diameter The acetabulum, 0.11—0.14 mm. in diameter, *i.e.*, nearly equal to or slightly larger than the oral sucker, is situated in the posterior half of the body, just in front of the hinder third of body length.

The genital atrium, containing the male and the female openings, is situated on the left body margin in level with the pharynx. The excretory opening is situated on the ventral surface a little in front of the posterior extremity.

The muscular globular pharynx of 0.03—0.065 × 0.05—0.07 mm. size is followed by a short œsophagus of 0.06—0.1 mm. length which bifurcates just in front of the ovary, in level with the junction of the pars prostatica and the ductus ejaculatorius. The intestinal cæca, usually of equal length, are short with moderately divergent extremities, ending blindly much in front of the acetabulum. They rarely extend beyond the posterior ends of the ovary and the cirrus sac.

The testes are massive structures, rounded or ovoid in shape, situated somewhat asymmetrically one on each side immediately in front of the centrum of the acetabulum. The right testis, 0.1—0.23 × 0.08—0.18 mm. in size, is usually a little larger than the left testis and is separated from the right body margin by the anteriorly passing coils of the uterus. The left testis, 0.1—0.23 × 0.08—0.1 mm. in size, is pushed somewhat caudad by the well-developed cirrus sac which lies in front and is separated from the latter and the acetabulum by the outgoing coils of the uterus. The vasa efferentia arise as delicate tubes, one from the posterior inner end of each testis, and run more or less transversely in front of the acetabulum to enter the vesicula seminalis through a small and inconspicuous vas deferens. The cirrus sac, 0.3—0.36 × 0.06—0.09 mm. in size, is highly muscular and has a slight S-shaped curvature The coiled vesicula seminalis is divided by a prominent constriction into two distinct parts, *i.e.*, a basal swollen sac-shaped part of 0.11 × 0.08 mm size and an anterior tubular part of 0.08 mm. length and 0.02 mm. breadth. The pars prostatica is elongated and somewhat flask-shaped, measuring 0.1—0.16 × 0.03—0.04 mm in size. It narrows anteriorly to form the ductus ejaculatorius of 0.06—0.1 mm. length which is followed by a knob-like cirrus of 0.013 mm. length.

The ovary, 0'09—0'18×0'05—0'13 mm. in size, is situated somewhat in the median line, more to the right side, far in front of the acetabulum and close behind the intestinal ·fork partly overlapping the right intestinal cæcum. Usually it has a regular outline with entire margin but sometimes it is lobed The receptaculum seminis, 0'1×0'04 mm. in size, is flask-shaped, situated transversely or obliquely, to the right side, close in front of the acetabulum. The Laurer's canal, 0'02 mm. in diameter, arises as a curved tube from the neck of the receptaculum seminis and runs posteriorly to open on the mid-dorsal surface in the region of the acetabulum.

The vitellaria are composed of usually an equal number of 4 – 8 large, pear-shaped follicles, each of 0 05—0'09×0'02—0'05 mm. size. The left vitelline gland lies close to the median line, behind the intestinal bifurcation, in the space between the cirrus sac and the ovary. The right vitelline gland lies close to the right body margin and slightly cephalad to the left gland. The two vitelline ducts run posteriorly and unite together to form the common vitelline duct to the right side of the ventral sucker. The common vitelline duct travels forward to form the yolk reservoir situated in front near the junction of the receptaculum seminis with the oviduct, in the space between the ovary and the acetabulum. A diffuse shell gland mass lies median, just in front of the acetabulum.

The descending part of the uterus commences near the left side of the acetabulum and forms several longitudinal and transverse loops, extending from the left testis to the posterior end of the body. Behind the acetabulum it passes into a transverse loop which extends forwards to the right side in the form of a longitudinal loop right up to the pharynx and then turns downwards forming two or three loops near the hinder end on the same side before it crosses over again to the left side to join the metraterm of 0'15×0'018 mm. size, which crosses the cirrus sac to lie close to its right side. In fully mature specimens, the coils of the uterus as described above are indistinguishable and the whole uterus appears as a mass of eggs. The eggs are dark brown in colour, oval and operculate, measuring 0'023 – 0'025×0'013 mm. in size.

The V-shaped excretory bladder consists of two broad cornua and a very small median stem. Both the cornua extend up to the level of the acetabulum and are slightly constricted in the middle of their length. The excretory pore lies on the ventral surface a little in front of the posterior end.

Of all the species of the genus *Pleurogenes* Looss *P. sitapurii* n. sp. is closely allied to *P. solus* Johnston 1912 in the shape and size of its body, position of the suckers and the genital pore and in the vitelline glands being composed of a few large follicles. It differs, however, from *P. solus* in the length of the œsophagus and the intestinal cæca, position and size of the gonads, size and number of the vitelline follicles, characteristic arrangement of the uterine coils and the position of the excretory pore.

### Systematic Discussion on the Genus Pleurogenes, Looss, 1896.

The genus *Pleurogenes* Lss. is parasitic in amphibia except *P. tener* which is described from a reptile—*Chamaeleo basiliscus* and *P. minus* which is parasitic in the intestine of a fish—*Esox lucius*. While the position of *Pleurogenes* as the typical genus of the sub-family *Pleurogenetinæ* needs no discussion a revision of its scope seems to be necessary.

Stafford in 1904 established the genus *Loxogenes* for *Dist. arcanum* Nickerson 1900 "on account of its genital opening being situated on the ventral surface, midway between the left intestinal cæcum and the body margin." This is the only feature which separates *Loxogenes* from *Pleurogenes*. But the genital pore does not lie exactly on the body margin in several other species of *Pleurogenes* such as *P. sphericus* and *P. intermedius*, in which it occupies a position far inwards to the left body margin. It is, therefore, necessary to drop this genus which contains species closely related to all the other species of the genus *Pleurogenes*.

Travassos in 1921, according to the suggestion made by Stafford in 1904, created a new genus *Pleurogenoides* for such species of the genus *Pleurogenes* as have short intestinal cæca (never extending behind the acetabulum) and retained the genus *Pleurogenes* for *P. claviger*. In his papers published in 1930 and 1931 he has maintained *Pleurogenes* and *Pleurogenoides* as distinct genera. Two genera can be accepted only so long as the generic differences between them are of absolute value and the intermediate forms connecting them do not exist. As the genera *Pleurogenes* and *Pleurogenoides* are now connected by such intermediate species as *P. orientalis* n. sp. *P. intermedius* Isaitschikow and *P. lobatus* Ozaki it appears necessary to drop the genus *Pleurogenoides*. I accordingly drop the genus *Pleurogenoides* and assign the species belonging to it back to the genus *Pleurogenes* Looss.

In splitting up the genus *Pleurogenes* into two subgenera Mehra and Negi have recognized the differences between the two groups of species, without losing sight of their close relationships. It is certainly a convenient arrangement which provides for a systematic grouping of a large number of species belonging to one genus. It may be pointed out that *P. orientalis* n. sp. is one of the intermediate species which connects the two subgenera *P. (Pleurogenes)* and *P. (Telogonella)*.

In the light of our recent knowledge of the genus the diagnosis of *Pleurogenes* as given by Mehra and Negi needs a certain amount of modification.

The amended diagnosis is as follows:

*Diagnosis.*—Body oval, elliptical, oblong or somewhat spherical; size small; acetabulum usually situated about the middle of body rarely in front or behind it. Oesophagus absent, short or long; length of intestinal cæca

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extremely variable. Genital pore situated on ventral or dorsal surface, near or on the left (rarely dextral) body margin, in front of or in level with intestinal bifurcation except in *P. lobatus* where it is behind·it Testes two, regular, except in *P. lobatus* (lobed), situated symmetrically, one on each side, or obliquely one behind the other, in level with, in front of or behind the acetabulum. Ovary regular or lobed, usually pretesticular rarely in level with the testes, dextral or median, near or in front of the acetabulum. Cirrus sac enclosing coiled vesicula seminalis and well-developed pars prostatica present. Vitelline follicles confined to the anterior bodyhalf. Uterine convolutions usually confined to the posterior half, rarely extending up to the level of the pharynx. Excretory bladder V-shaped with or without a short median stem or Y-shaped with the main stem much longer than the cornua as in *P. bicolor* Krull 1933; excretory opening terminal or subterminal. Eggs small, and numerous, measuring, 0 02 − 0˙037 × 0 01 − 0˙016 mm. in size.

Host—usually amphibia only exceptionally fishes and reptile

Habitat—the gut of the host except *P. arcanum* which lives in cysts around the pylorus, surface of liver and neck of the urinary bladder of frogs.

## Key to the Sub-genera of Pleurogenes, Looss 1896.

Intestinal cæca confined to the first half of body and not extending behind the acetabulum  ... Sub-genus *Pleurogenes.*

Intestinal cæca extending behind the acetabulum into the posterior half of body  ...  ... Sub-genus *Telogonella.*

## Key to the Species of the Sub-genus Telogonella

1. The main stem of the excretory bladder much longer than the cornua  ...  ... *P bicolor.*
   The main stem of the excretory bladder much smaller than the cornua ...  ... 2

2. Gonads lobed  ...  ...  ... *P. lobatus.*
   Gonads with entire margins  ...  ... 3

3. Testes obliquely situated, one behind the other  ...  ...  ...  ... *P. loossi.*
   Testes symmetrically situated, one on each side  ..  ...  ...  ... 4

4. Testes overlapping the cæca and situated a little in front of their blind ends  .., *P. intermedius*

Testes situated behind the termination of the
  intestinal cæca     ...     ..     ...  5

5.  Intestinal cæca end a little behind the aceta-
      bulum, in front of the posterior third body-
      length     ...     ...     ...     ...  *P. orientalis.*
    Intestinal cæca extend far behind the aceta-
      bulum, never ending in front of the ⅜th
      bodylength     ...     ...     ...  *P. claviger.*

## Key to the Species of the Sub-genus Pleurogenes

Acetabulum distinctly post-equatorial     ...  A
Acetabulum equatorial or pre-equatorial     ..  B

*A.*  Oesophagus absent     ...     ...     ...  *P sphericus.*
    Oesophagus present     ...     ..     ...  1

1.  Intestinal cæca extend up to the acetabulum  *P. solus.*
    Intestinal cæca do not extend up to the ace-
      tabulum ...     ...     ...     ...  2
2.  Excretory pore terminal     ...     ...  *P. tener.*
    Excretory pore subterminal     ...     ...  *P. sitapurii.*

*B.*  Ovary extra-cæcal     ...     ...     ...  1
    Ovary not extra-cæcal ...     ...     ...  2
1.  Intestinal cæca extend up to the acetabulum  *P. minus.*
    Intestinal cæca stop in front of the acetabulum  *P. medians.*
2.  Oesophagus present     ...     ...     ...  3
    Oesophagus absent     ...     ...     ...  4
3.  Genital atrium opens on the left body margin  *P. freycineti.*
    Genital atrium opens subterminally half way
      between the left intestinal cæcum and
      body margin     ...     ...     ...  *P. arcanum.*
4.  Testes situated anterior to the ends of the
      intestinal cæca     ..     ...     ...  *P. taylori.*
    Testes lie behind the ends of the intestinal cæca  5
5.  Vitellaria consist of a few large follicles ;
      pre-cæcal     ...     ...     ...  *P. stromi.*
    Vitellaria consisting of a large number of
      small follicles scattered all over the cæca
      and meeting in the median line     ...  6
6.  Acetabulum larger than the oral sucker     ...  *P. gastroporus.*
    Acetabulum of the same size as the oral
      sucker     ...     ...     ...     ...  *P. gastroporus var.*
                                                *equalis.*

## Systematic Discussion and Revision of the Family
## Lecithodendriidae.  Odhner 1911.

Looss in 1896 created the subfamily *Lecithodendriinæ* to include the genera *Lecithodendrium, Phanaropsolus* and *Pycnoporus.* Later in 1899 he considered the resemblance between *Lecithodendrium* and *Brachycælium* to be so close that he dropped the subfamily *Lecithodendriinæ* and assigned all the genera to the subfamily *Brachycæliinæ* Looss. Luhe in 1909 adopts the latter course in the "Susswasserfauna Deutschlands". Two years later Odhner reshuffled the whole arrangement and removed all the genera except *Brachycælium* from the *Brachycæliinæ* to the *Lecithodendriinæ* which then is the *Brachycæliinæ* minus *Brachycælium.* The *Brachycæliinæ*, containing *Brachycælium*, was assigned by him to the family *Dicrocælidæ* Cort 1919, Mehra and Negi 1926 and Mehra 1931 found this position untenable and assigned this subfamily to the family *Lepodermatidæ.*

The subfamily *Pleurogenetinæ* was established by Looss in 1899 to include the genera *Pleurogenes* and *Prosotocus.* The *Pleurogenetinæ* shows unmistakable affinities with the *Lecithodendriinæ* in the presence of a V-shaped excretory bladder, position of the acetabulum about the middle of the body, situation of the ovary near it to the right side or about the median plane and the disposition of the uterine convolutions. Further, the absence of a cirrus sac in *Ganeo* brings the *Pleurogenetinæ* closer to such genera of the *Lecithodendriinæ* as *Lecithodendrium, Prosthodendrium, Acanthatrium* and *Pycnoporus*, etc. The important differences between the two subfamilies lie in the position of the genital pore and the host. Odhner in 1911 recognised the close affinities between the two subfamilies and brought them together under one and the same family *Lecithodendriidæ.* Though this view of the relationship has never been questioned, the recent work of Fuhrmann in 1928 and of Travassos in 1922, 1928, 1930 and 1931 has caused some confusion in the limits of the two subfamilies owing to the unnatural grouping of the genera under them. Unfortunately both these authors have not given any indication of the reasons for assigning the various genera to the two subfamilies.

Fuhrmann 1928 includes under *Lecithodendriinæ* the genera *Lecithodendrium, Pycnoporus, Phanaropsolus, Parabascus, Mesodendrium, Acanthatrium, Limatulum* and *Castroia,* and under the *Pleurogenetinæ* the genera *Pleurogenes, Loxogenes, Prosotocus, Mosesia, Postorchigenes, Brandesia, Pleurogenoides, Ganeo, Eumogacetes* and *Anchitrema.* Travassos in 1922 while describing a new species of *Eumagacetes—E. perodiosus* from the cloaca of *Pioya cajaula,* Brazil—raised the genus to the rank of a family—*Eumagacetidæ.* In 1928 he included the genera *Lecithodendrium, Paralecithodendrium, Acanthatrium* and *Castroia* under *Lecithodendriinæ.* In 1930 under the *Pleurogenetinæ* he included the genera *Pleurogenes, Pleurogenoides, Cryptotrema, Limatulum, Loxogenes, Prosotocus*

*Brandesia*, *Phanuropsolus*, *Mosesia* and *Parabascus*. In the last paper he also referred the genus *Ganeo* to the subfamily *Lecithodendriinæ*.

From the above lists it appears that the classification of the family *Lecithodendriidæ* is entirely arbitrary and that a revision of the family is needed.

The genera *Mesodendrium* Faust 1919 and *Lecithodendrium* Looss 1896 have already been referred as synonymous by Dollfus in 1931. The untenability of the genera *Loxogenes* Stafford and *Pleurogenoides* Travassos has been made clear in the systematic discussion before and the genus *Ganeo* has been already assigned by me 1933 to the *Pleurogenetinæ*. The family *Eumagacetidæ* Travassos 1922 based on the length of the intestinal cæca and the extent of the vitellaria—characters which vary within wide limits in the family *Lecithodendriidæ*—cannot be maintained. I, therefore, refer the genus *Eumagacetes* to the *Lecithodendriinæ* in which it was first included.

The classification of the genera of the *Lecithodendriidæ* into subfamilies should not be based on (*a*) the length of the intestinal cæca, (*b*) the extent of the vitellaria, and (*c*) the position of the testes because they are very variable in this family. The only features which show constancy and have little variability are the position of the genital pore and the host. The length of the intestinal cæca varies widely in such closely related genera as *Eumagacetes*, *Lecithodendrium*, *Prosotocus*, *Mehraorchis* and *Pleurogenes* and even in the different species of the last genus; so does also the extent of vitellaria in *Lecithodendrium*, *Prosotocus*, *Prosthodendrium*, *Eumagacetes*, *Pleurogenes*, *Mehraorchis* and *Cryptotropa*. The position of the testes also presents the same condition in different genera. But the position of the genital pore, sinistral, dextral or median and the host are the features which should be recognised as the basis of the division into the two subfamilies. Those genera which have the genital pore situated to the left (exceptionally to the right) of the median line either in front or in the neighbourhood of the acetabulum and are usually parasitic in fishes, amphibia and reptiles are separated under the subfamily *Pleurogenetinæ* and the others which have the genital pore situated in or about the median line and are parasitic in reptiles, birds and mammals are included under the *Lecithodendriinæ*. The genus *Parabascus* which has the genital pore to the left side and is parasitic in bats combines the characters of both the subfamilies. In this case I should point out that the nature of the host should not be considered of very great importance, as it is probable that the insect larvæ through which the larval stages of the members of the *Lecithodendriidæ* are passed, form the food common to hosts of different groups such as amphibia and bats. For similar reasons Braun also cautioned against attaching undue importance to widely different hosts of closely related species, *i.e.*, *Crepidostomum laureatum* Zedar, parasitic in fish and *C. mitoecus*, parasitic in bats.

In view of the several new forms which have been described in recent years the diagnosis of the family *Lecithodendriidæ*, as given by Odhner in 1911 needs to be modified and the scope of its subfamilies redetermined.

## Emended Diagnosis of Lecithodendriidae, Odhner, 1911

Body small rounded or fairly long and elongated; ventral sucker in the middle of the body or not far from it; spines present or absent. Prepharynx present or absent; pharynx present; œsophagus present or absent; intestinal cæca of varying length. Testes situated usually symmetrically, one on each side, rarely obliquely one behind the other in different regions of the body. Cirrus sac present or absent or represented by a pseudocirrus sac. Ovary usually situated to the right side, sometimes in the median line, not far from the ventral sucker; a small receptaculum seminis and Laurer's canal present. Vitellaria of variable extent, consisting of only a few or numerous follicles, confined either to definite regions or scattered all over. Uterus strongly convoluted convolutions usually confined to the postacetabular region, rarely extending as far forwards as the pharynx; eggs numerous, measuring 0·015—0·06 mm in size. Excretory bladder V-shaped with or without a short median stem, rarely Y-shaped with the main stem larger than the cornua.

Parasitic in insect eating vertebrates, from fishes to mammals.

## Subfamily—Lecithodendriinae, Looss char. emend.

Body elongated or rounded, moderately large or small, suckers well developed; spines present or absent. Intestinal cæca only exceptionally extend beyond the acetabulum as in *Eumagacetes* and *Anchitrema*. Testes more or less symmetrically situated; genital pore median, situated in front or in the neighbourhood of the acetabulum. Eggs small and numerous, 0·017—0·03 mm. in size. Excretory bladder V-shaped.

Parasitic in reptiles, birds and mammals.

## Subfamily—Pleurogenetinae, Looss, char, emend.

Body elliptical, elongated, oval or rounded, size small; suckers not particularly muscular; body partly or wholly beset with spines. Intestinal cæca of variable length. Testes variable in position, usually symmetrically situated, one on each side; rarely obliquely placed one behind the other; cirrus sac or pseudocirrus sac present or absent. Genital pore sinistral, rarely dextral, marginal or submarginal; in front or in the neighbourhood of the acetabulum. Vitellaria of varying extent. Uterus much convoluted, generally confined to the postacetabular region, exceptionally extending as far forwards as the pharynx; metraterm present or absent. Excretory bladder V-shaped with or without a short median stem, exceptionally Y-shaped. Eggs usually of deep brown colour, 0·02 – 0·06 mm. in size.

Parasitic in fishes, amphibia and reptilia except *Parabasous* which is found in bats.

Family — *Lecithodendriidæ* Odhner 1911.
Subfamily — *Lecithodendriinæ* Looss 1896.
Genera — 1. *Lecithodendrium* Looss 1896.
      2. *Pycnoporus*     Looss 1899.
      3. *Phaneropsolus*  Looss 1899.
      4. *Anchitrema*     Looss 1899.
      5. *Eumagaceles*   Looss 1899.
      6. *Acanthatrium*  Faust 1918.
      7. *Limatulum*    Travassos 1926.
      8. *Castroia*     Travassos 1928.
      9. *Mosesia*     Travassos 1928.
    10. *Prosthodendrium* Dollfus 1931.
Subfamily — *Pleurogenetinæ* Looss 1899.
Genera — 1. *Pleurogenes*     Looss 1896.
      2. *Prosotocus*    Looss 1899.
      3. *Brandesia*    Stossich 1899.
      4. *Ganeo*       Klein 1905.
      5. *Parabascus*   Looss 1907.
      6. *Cryptotropa*  Strand 1931.
      7. *Postorchigenes* Tubangui 1928.
      8. *Mehraorchis*  Srivastava 1933.

### EXPLANATION OF PLATES

Fig. 1—Ventral view of *Mehraorchis ranarum.*
Fig. 2 — Do.   Do.  *Pleurogenes orientalis.*
Fig. 3—Dorsal view of *Pleurogenes sitapurii.*

### LETTERING

| | | | | | |
|---|---|---|---|---|---|
| Act | ... | Acetabulum. | Oes. | ... | Oesophagus. |
| C | ... | Cirrus. | Oot. | ... | Ootype. |
| E. bl. | ... | Excretory bladder. | O. s. | ... | Oral sucker. |
| E. bl. c. | ... | Cornua of Excretory bladder. | Ph. | ... | Pharynx. |
| E. p. | ... | Excretory pore. | P. gl. | ... | Prostate glands. |
| G. a. | ... | Genital atrium. | R. sm. | ... | Receptaculum seminis. |
| I. c. | ... | Intestinal cæcum | T. | ... | Testis. |
| Mtm. | ... | Metraterm. | Ut. | ... | Uterus. |
| Ov. | ... | Ovary. | V. sm. | ... | Vesicula seminalis. |
| P. p. | ... | Pars prostatica. | Vit. d. | ... | Vitelline duct. |

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Fig. 1.

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Fig. 2.

1 m. m.



Fig. 3.

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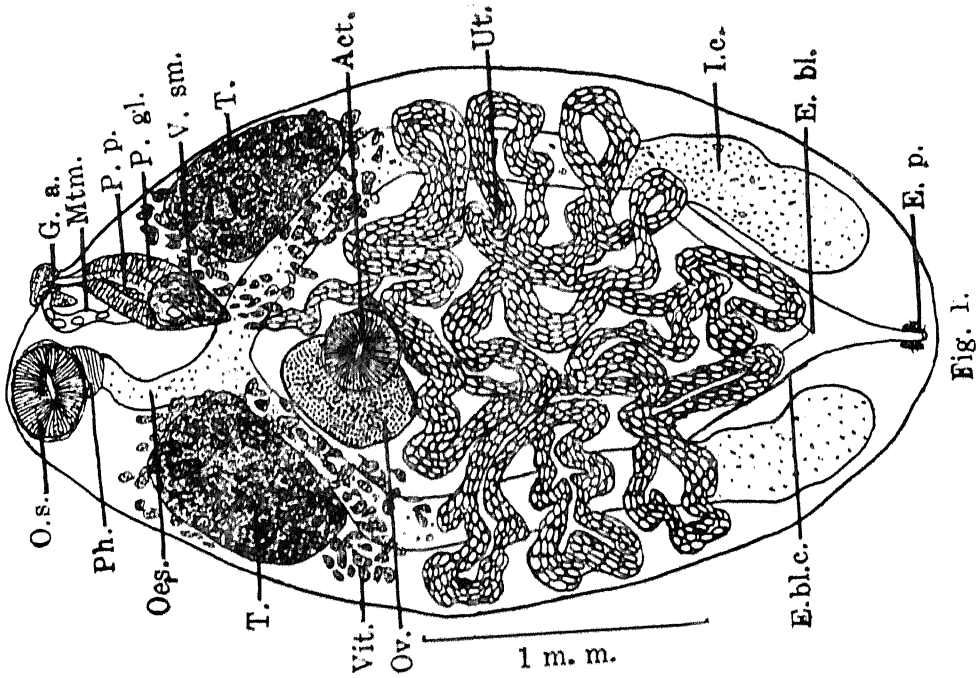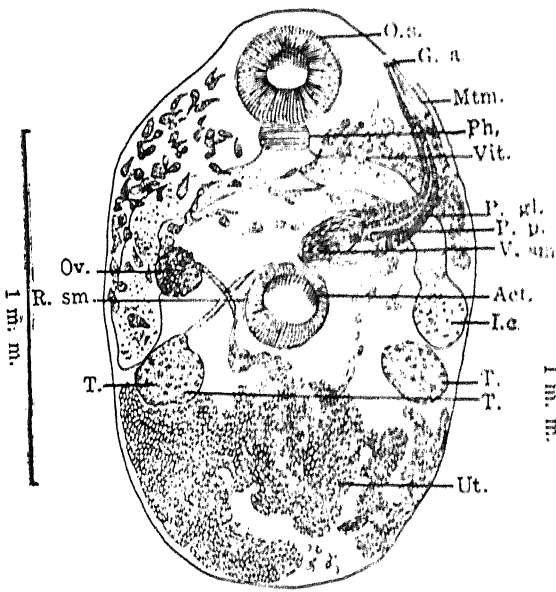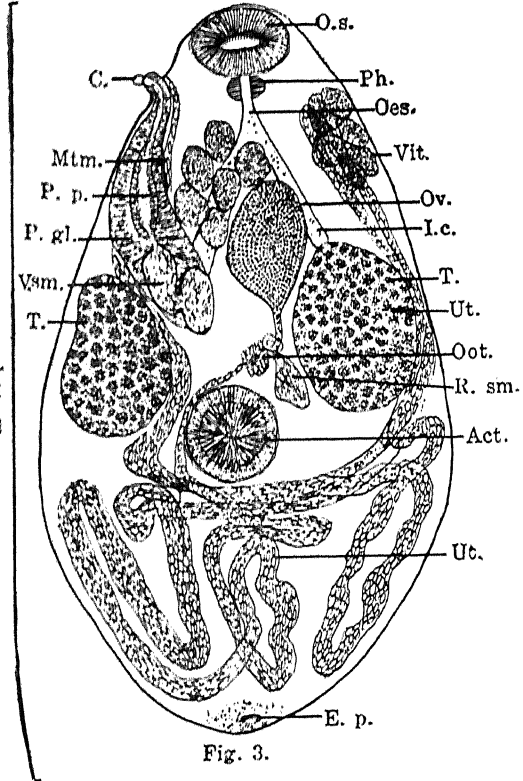
# ON THE β-RAY ACTIVITY OF RADIOACTIVE BODIES

## *(Preliminary Communication)*

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## Introduction

The β-ray activity of radioactive bodies has up till now proved to be a baffling problem. The points at issue are summarised in Gamow's *Constitution of Atomic Nuclei*, pp. 52—54, and in *Radiations from Radioactive Bodies* by Rutherford, Chadwick and Ellis. They are also discussed at some length by Bohr in his *Faraday Lecture* (Feb. 1932). We shall later quote freely from Bohr, but some fundamental difficulties may be pointed out at the outset.

The older view of the constitution of the nucleus was that it should be regarded as composed of $A$ protons ($A$=mass number) and $A - Z$ electrons ($Z$= nuclear charge). A large number of these protons and electrons may exist in the compound form of α particles ($4p + 2e$) or some other composite structures. But even allowing for these, the existence of a number of free electrons had to be postulated inside the nucleus. On the other hand, the evidence of hyperfine structure, as was first pointed out by de Kronig, definitely proves that the electron cannot exist in the free state in the nucleus, for then the magnetic moment of the nucleus should have the magnitude of the Bohr magneton, while the hyperfine structure of spectral lines definitely shows that the moment has the magnitude of the protonmagnet ($\frac{1}{1838}$ times the Bohr-magneton). At the present time, it is almost universally held that the nucleus consists of $Z$ protons, and $A - Z$ neutrons, but it is quite possible that a number of these are combined in the form of α-particles, deutons, etc. *The nucleus contains no electrons free or bound.* [1,2]

But this conclusion is seemingly at variance with the observed fact that in a β-ray disintegrations the nuclei are observed to eject high speed electrons spontaneously. The situation is therefore paradoxical. Bohr puts it as follows :—

"Strictly speaking, we are not even justified in saying that a nucleus contains a definite number of electrons, but only that the negative

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electrification is equal to a whole number of units and in this sense, the expulsion of a β-ray from a nucleus may be regarded as the creation of an electron as a mechanical entity "

In a later passage, Bohr describes the other difficulties as follows :—

"As regards this last question, much theoretical interest has recently been aroused by the peculiar features exhibited by the β-ray expulsions. On the one hand, the parent elements have a definite rate of decay, expressed by a simple probability law, just as in the case of the α-ray disintegrations. On the other hand, the energy liberated in a single β-ray disintegration is found to vary within a wide continuous range, whereas the energy emitted in an α-ray disintegration, when due account is taken of the accompanying electromagnetic radiation and the mechanical energy conversion, appears to be the same for all atoms of the same element."

To the above remarks of Bohr, the following may be added :—

(a) The β-ray disintegration has been observed not only in the case of heavy elements, but also in the light elements potassium and rubidium (or rather the isotopes $K^{41}$ and $Rb^{87}$). In the case of β-ray bodies associated with the main groups (U, Th, Ac), the life of β-ray bodies is found to vary from 16 years (RaD) to a few minutes, but the light elements $K^{41}$ and $Rb^{87}$ possess lives comparable with those of some long-lived heavy radioactive bodies. The life of $K^{41}$ has been estimated to be $7.5 \times 10^{10}$ years that of $Rb^{87}$ to be $10^{11}$ years.[3] It is quite possible that there may be a number of β-ray elements possessing longer lives which are still undiscovered, as the activity of such bodies is likely to be extremely feeble, and difficult of detection. In support of our view, we may cite the case of Ac, RaD ... which were long regarded as undergoing *rayless* changes. They are not actually rayless, but the β-rays are exceedingly feeble, on account of the long life of these bodies.

*From these remarks it will be clear that there is no essential difference between the orders of ranges of the lives of β-ray and α-ray bodies.*

(b) Ellis[4] has shown in numerous papers that one β-particle is emitted per one disintegrating atom, so that the possibility that the expulsions are due to some external agency seems to be ruled out. They are spontaneous processes like α-ray disintegration.

(c) The distribution of energy in the β-ray spectrum —This point has formed the subject of investigation by a large number of workers. The curves bear some resemblance to Planck's curve for blackbody radiation but unlike that curve, it has got a limit on the high energy side and the maximum is ill-defined. They also present some similarity to the curves obtained by Kuhlenkampf on the distribution of intensity in the continuous X-ray spectrum.

There has been an idea that the β-rays are probably emitted with quite a definite energy from the nucleus, but in its passage through the outer shell

of electron, it suffers diminution in energy owing to collision or scattering but this view has been disproved by Ellis.[5] Lately, attempts have been made to determine the maximum energy as accurately as possible and to deduce from it a relation similar to that of Geiger and Nutall for α-ray bodies.

The latest exponent of this idea is Sargent[6] who found in a recent paper that every β-ray disintegrating atom is distinguished by having a definite end-point in its energy-spectrum But a reference to his figures shown in Table VI, p. 670, and his curves on p. 671, Fig. 2, shows that there is not much evidence of a relation. For the points lie on three distinct curves, and the radioactive bodies belonging to the same family do not lie on the same curve. Secondly, if the Geiger-Nutall law for α-ray bodies is expressed in the form $\lambda = aE^n$ where E = energy of the α-particle varying between 4 to 8 million electron-volts, $\lambda$ varies from $10^5$ sec$^{-1}$ (Th C') to $10^{-18}$ sec.$^{-1}$ (U), $n$ is found to vary from 65 to 100. But for the β-ray bodies, E varies from $3.5 \cdot 10^4$ evs to $3.15 \times 10^6$ evs, $i.e$, a range of about 1 to 100, but $\lambda$ varies from $10^{-2}$ sec$^{-1}$ to $10^{-9}$ sec.$^{-1}$ and if $\lambda$ be put $= bE^n$, $n$ varies from 3 to 7. The attempt to trace a causal connection between the decay constant and the maximum β-ray energy does not appear to have been successful. We shall see later that no such causal connection is expected.

*The fact that the β-ray bodies follow the same law of decay as α-ray bodies can, however, point to only one conclusion,* i.e., *the phenomenon is due to the leakage of α-rays through a potential barrier, but somehow the α-ray does not leave the nucleus, but a ν-ray is generated in its place.*

Bohr weighs the probability that the continuous β-ray energy spectrum may be due to differences in the energy contents of the individual parent atoms leading to small and undetectable differences in their mass, but finally decides against this view. The following are his words.

"Unless the expulsion of β-rays from atomic nuclei, contrary to expectation, is not a spontaneous process but caused by some external agency, the application of the principle of energy conservation to β-ray disintegration would accordingly imply that the atoms of any given radio element would have different energy contents. Although the corresponding variations in mass would be far too small to be detected by the present experimental methods, such definite energy differences between the individual atoms would be very difficult to reconcile with other atomic properties. In the first place, we find no analogy to such variations in the domain of non-radioactive elements. In fact, as far as the investigations of nuclear statistics go, the nuclei of any type, which have the same charge and within the limits of experimental accuracy, the same mass, are found to obey definite statistics in the quantum mechanical sense, meaning that such nuclei are not to be regarded as approximately equal, but as essentially identical. This conclusion is the more important for our argument, because in absence of any theory of the intra-nuclear

electrons, the identity under consideration is in no way a consequence of quantum mechanics, like the identity of the extra-nuclear electronic configurations of all atoms of an element in a given stationary state, but represents a new fundamental feature of atomic stability. Secondly, no evidence of an energy variation of the kind in question can be found in the study of the stationary states of the radioactive nuclei involved in the emission of σ and γ rays from members of a radioactive family proceeding or following a β-ray product. *Finally, the definite rate of decay which is a common feature of α- and β-ray disintegrations points even for a β-ray product, to an essential similarity of all the parent atoms,* in spite of the variation of the energy liberated by the expulsion of the β-ray. In absence of a general consistent theory embracing the relationship between the intrinsic stability of electrons and protons and the existence of the elementary quanta of electricity and action, it is very difficult to arrive at a definite conclusion in this matter."

We have quoted this passage in full, because after this paper was written, we came across a paper by Beck[7] where this idea of hypothetical differences in the energy contents of the individual parent atoms resulting in small and undetectable differences in their mass has been revived to account for the continuous energy distribution amongst the ejected β-rays.

Finally, in order to explain events, Bohr wants to sacrifice the law of conservation of energy and suggests the following process:

"At the present stage of atomic theory, however, we may say that we have no argument, either empirical or theoretical, for upholding the energy principle in the case of β-ray disintegrations, and are even led to complications and difficulties in trying to do so. Of course, a radical departure from this principle would imply strange consequences, in case such a process could be reversed. Indeed if, in a collision process, an electron could attach itself to a nucleus with loss of its mechanical individuality, and subsequently be recreated as a β-ray, we should find that the energy of this β-ray would generally differ from that of the original electron. Still just as the account of those aspects of atomic constitution essential for the explanation of the ordinary physical and chemical properties of matter implies a renunciation of the classical ideal of causality, the features of atomic stability, still deeper-lying, responsible for the existence and the properties of atomic nuclei, may force us to renounce the very idea of energy balance."

The above short summary will probably convey some idea regarding the complexity of the problem.

## 2. Electrofission of Light Quanta

It appears that the β-ray disintegration admits of a rather simple interpretation on the basis of the recent experiments by Anderson and Neddermeyer,[8] Meitner and Hupfeld[9], Curie and Joliot[10] on the production of pairs

of positrons and electrons by impact of hard γ-rays with atomic nuclei  As the description of this fundamental discovery, which promises to throw a flood of light on nuclear physics, is still scattered over the pages of many scientific journals, we try to give a connected account of it here.  Skobelzyn[11] was the first to use vertical Wilson Chambers placed within a horizontal magnetic field for photographing the track of cosmic rays.  He found that the cosmic rays gave rise to tracks of β-rays possessing extremely high energy.  In some cases, the mass-equivalent of the energy was as great as 50 ~ 100 times the rest-mass of the electron.  On repeating these experiments, Anderson[8] found that in addition to the tracks due to high energy β-rays there were others possessing equal curvature, but bent in the opposite direction.  From the nature of ionisation along these tracks, it was clear that they were due to particles of the same type as electrons, but possessing an opposite, i.e., a plus charge.  To this particle, which is the exact positive analogue of the electron, the name *positron* was given.  Subsequently Meitner and Hupfeld[9] obtained similar paired tracks of electrons and positrons by taking Wilson photographs of Be-radiations impinging on Pb and Anderson and Neddermeyer and Curie and Joliot[10] showed that even the hard γ-rays from ThC'' having the energy 2·6 *mevs* can give rise to such paired tracks (*mevs* stands for million electron volts).

### How are the pair positron and electron produced ?

Anderson and Neddermeyer, and Blackett and Ochialini[11] further showed that this production of " paired ions " accounts for a number of unexplained facts.  Gray and Tarrant[12] had previously shown that hard γ-rays show an anomalous absorption which is not accounted for by the Klein-Nishina formula for scattering.  The anomalous absorption was found by them to start at the γ-ray energy 2 to 3 mevs.  Later Gentner[13] fixed the limit at 1·2 mevs.  We have to remember in this connection that $m_0c^2$, the rest energy of the electron corresponds to $5 \times 10^5$ *evs* and thus the energy of a pair of electron and positron at rest is equivalent to 1 *mevs*  Hence there is a connection between the beginning of anomalous absorption, and the production of " paired ions." Blackett and Ochialini[11] suggested that within the nucleus, the γ-ray is split up, under the intense electric field, into a pair consisting of a positron and an electron.  Oppenheimer and Plessett[14] regarded the phenomenon as a photo-electric effect, the γ-ray quantum lifting an electron occupying one of Dirac's negative energy states into a positive energy state, thus simultaneously creating an ordinary electron and a "hole" which according to the ideas of Dirac will correspond to the positron ⟨*vide* § 3⟩.  Curie and Joliot[10] have proposed to denote this phenomenon as " *materialisation of quanta.*"

Blackett further showed that the hypothesis of the splitting of the quantum inside the nucleus explains another interesting observation by Gray[12] and others.  The former has subjected the nuclei of many atoms to hard

γ-rays from ThC'' and found that the nuclei were thereby excited to a fluorescent radiation of approximate wavelengths 12X. units and 24X. units The first possesses an energy of 1 *mers* and the second ½ *mers*. According to Blackett, though the γ ray may split up inside the nucleus into a pair of positrons and electrons, but the two may again combine either inside the nucleus or just outside. When they combine inside the nucleus only one quantum of energy 1 *mers* units may be produced. If they combine outside, two quanta each of energy 0·5 *mers* units will be produced.

We are of opinion that the phenomenon of conversion of a γ-ray into a pair of ions of opposite sign, confirmed by so many investigators in different parts of the world, should be designated by a more expressive term than Curie and Joliot's *Materialisation of Quanta* and the round-about phraseology about holes, etc., borrowed from Dirac's theory should be avoided, and we have ventured to suggest the term ' *Electrofission of Light Quantum* ... which clearly expresses the idea that under the influence of the nuclear fields, the quantum of energy undergoes a ' *fission* ' into elementary charges of opposite sign, the balance of energy being distributed as kinetic energy amongst the two products in a way which is still to be determined. The possibility of the reverse process of two charges neutralising each other in a direct collision has been postulated by many astrophysicists in a slightly different form. But when these predictions were made, the positive unit of electricity was known to be always associated with the mass in a proton, and nobody could conceive of a positron, hence they always talked of annihilation of proton and electron, but the hypothesis has always lacked vigour on account of want of experimental proof. The process as now actually found is different from the early hypothesis about annihilation in many other points.

### Theoretical Predictions about Positron

It may be added at this stage that grounds for the advent of the positron were to some extent prepared by the predictions of Dirac[15] from his relativistic theory of the electron. In this he was first led to postulate the existence of an elementary particle having the charge-$e$ but possessing the negative energy $-me^2$. Such a particle (the anti-electron) would possess very weird properties which have not been observed. We quote from Gamow.

" For such particles the force and acceleration are directed in opposite directions. If two electrons, one of 'positive' and the other of 'negative' mass, meet then the first will be repelled and the second attracted to the other one; both electrons will fly away one behind the other with infinitely increasing velocity, giving an amusing picture of electronic races."

Later, Dirac developed a theory of 'holes' to account for 'positive charges'. He postulated that in Nature all the negative energy states are usually fully occupied, but sometimes a hole may appear. A positive energy

electron will then jump into the hole, resulting in the neutralisation of charges and release of the energy $> 2\, m_0 c^2$ as radiation in the form of one or two quanta. The process is thus equivalent to the so-called annihilation of charges. The 'hole' can be identified as a "unit positive charge". But it could not be identified with the 'proton' because the mass of the proton is 1836 times heavier than that of the 'hole'. The discovery of the positron exactly corresponds to Dirac's hole, but sweeps away the misleading ideas about particles capable of possessing "negative energy-state". These ideas are not a little responsible for creating confusion in contemporary scientific thought. Instead of an anti-electron with a negative energy we have now a straight-forward positive analogue to the electron with positive charge and positive energy.

## The Proton

The question of the nature of the Proton now becomes a problem. According to one view, the proton is not a fundamental particle but is a compound of the neutron and the positron. If this view be correct, the neutron is merely 'mass' possessing an inherent tendency to capture positrons, but behaving in a different way towards electrons which they cannot capture for if this could take place, we could obtain a negative proton. There is also certain amount of experimental evidence in favour of this view. Anderson and Neddermeyer, as well as Curie and Joliot found in their experiments on *Electrofission* of ThC′ γ-ray quantum that more electrons are obtained than positrons, Curie and Joliot[10] give the following figures.

*Number of positrons per 100 electrons (Magnetic field 1100 gauss).*

| Al | Cu | Pb | U |
|----|----|----|----|
| 5 | 18 | 30 | 40 |

But working with cosmic rays which can now be definitely taken to be super γ-rays, it has been found by Anderson as well as Kunze[16] that the number of positron tracks is equal to the number of electron tracks. These results, can be explained on the hypothesis that positrons are easily absorbed by the constituents of the nucleus, possibly neutrons, while electrons are repelled by them. Only very high energy positrons can resist capture by nuclei. Further, if the neutron, the electron and the positron are fundamental particles, they should possess the angular momentum $\frac{1}{2}\frac{h}{2\pi}$ (and be guided by Fermi-Statistics). The protons according to this view may have varying angular momentum depending upon the state of the combination between the neutron and the positron, a view which seems to be in agreement with the latest results of

Stern and Eastermann.[17] According to Chadwick,[18] however, the proton is probably fundamental, and the neutron is a "dipole" composed of the proton and the electron. As the difference of mass on the two views is of the order of ˙00054, the question cannot probably be ever determined by a precision estimation of masses, but only by investigation of the response of the neutron to light quanta. For, Chadwick's neutron being a dipole. would be highly reactive towards electromagnetic radiation, while the mere 'mass-neutron' is not expected to be reactive. Even on this point, we are not on very sure grounds, for according to one of us, the neutron is a magnetic dipole, composed of two free Dirac's magnetic poles separated by a distance of $\dfrac{e^2}{Mc^2}$ which is $\frac{2}{3}$ times the protonic radius, but these views have no effect on the present course of investigation.

Though not directly connected with the subject-matter of this article, it may be pointed out that the two views regarding the proton will have different consequences in astrophysics. According to many astrophysicists, hydrogen is found in abundance in many stars, and there is a likelihood that the chief constituent of all stellar matter is hydrogen. This must exist in the interior as protons. The proton, if it is a compound will be further broken up into the neutron and the positron, for the binding energy is small, between $10^4$ to $10^5$ evs, and even the smallest temperature ascribed to stellar interiors is suffi-cient for the complete breaking of the proton. The other (Chadwick's) view does not allow this breaking, for the proton being fundamental cannot be further subdivided. So on the first view the stellar core will consist of neutrons, positrons and electrons; while on the second view, it will consist of protons and electrons. This is fraught with far-reaching consequences. For the neutrons have been found to possess the remarkable property of passing through matter till they are stopped by the nucleus, and when they strike the nucleus, they excite radical changes in it, resulting in the emission of protons, γ-rays. α-particles. One of us is at present engaged in working out a model of a star whose interior is mainly composed of neutrons.

## Annihilation of Charges

In this connection, we may refer to the hypothesis about annihilation of matter advocated by Jeans and Eddington[19] to account for the source of stellar energy. A certain amount of vagueness is always attached to such hypothesis, for annihilation literally means to be reduced to nothing, but the process described here is very different from unalloyed nihilism on the part of fundamental particles, for when an electron and proton hit each other, a neutron and a γ-ray is produced. There is no violation of the principle of

conservation of energy or momentum, so nothing is annihilated except that the charges seemingly disappear. The energy of the γ-ray is available for supplying the stellar energy, but it is not yet known whether the mass of the neutron can be converted into energy. Again, when an electron and positron collide outside a nucleus an application of the principle of conservation of energy and linear momentum shows that two quanta must be produced in their place. If they collide inside the nucleus, there may be one quantum as the nucleus can bear certain amount of the shock and thus ensure the obedience to the law of conservation of momentum. In both these processes, there are more variables than equations, and hence the energy of the quanta cannot be uniquely determined. In none of these processes of collision there is either annihilation of mass, or energy, and not even of charges, for in the quantum formed, the two charges probably retain their individual existence as components of a dipole moving with the velocity of light, and they can again be separated when a "fission" takes place. This picture is very different from what is conveyed by Eddington's picturesque description of the phenomenon as a " joint suicide of the electron and the proton."

### 3. Explanation or β-Ray Activity

We shall now discuss how the β-ray activity can be explained. It is clear that if a γ-ray or supergamma (cosmic) ray coming from outside can split up inside the nucleus into an electron and a positron, it will be much more easier for a γ-ray, of sufficient energy, which is produced within the nucleus to undergo spontaneously such a process of electrofission. Of the pair produced, the electron will be ejected as a β-ray, but the positron cannot usually escape, for it will be prevented by the potential barrier from escaping when such barriers exist, or attach itself to some neutron which is present inside the nucleus. For we have already seen that the neutron has an affinity for the positron, but none for the electron. The net charge in any case will be increased by unity, as is observed in β-ray disintegration. It attaches itself to a neutron, γ-rays of small energy of the order of ·05 mevs would probably be given off, which are always observed in a β-ray disintegration. It is not difficult to account for the continuous distribution of β-ray energy, for the primary γ-ray while undergoing 'Internal electrofission' may have its energy divided between the pairs within wide limits and a certain amount of energy will be communicated to the nucleus  But exact mathematical calculations can be carried out only when more data are forthcoming. The problem of annihilation of two charges of opposite sign which is the converse of the present problem has been discussed by Dirac[20] Tamm, and Oppenheimer on the basis of Dirac's holes as positrons.

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According to the above view, the β-ray emission is only a secondary process, the primary phenomenon which starts the chain of events which we call a β-ray disintegration is the generation of primary γ-ray within the nucleus. We may now ask ourselves: how is this γ-ray generated? For this, a discussion of the recent theories of a α-ray disintegration is necessary.

It is now well known that classical mechanics offered no solution to the problems of radioactivity. Gamow, and Gourney and Condon first suggested methods for explaining many features of radioactivity from the standpoint of wave-mechanics. The methods were elaborated in great detail by Gamow who succeeded in achieving a good deal of success in explaining the essential features of α-ray disintegration and γ-ray origins. Very substantial contributions were also made by Laue, Fowler, Fowler and Wilson, Atkinson and Houtermans, Schrodinger and others.[21]

All these works suffer from the defect that we have as yet no sure knowledge of the structure of nucleus, i.e., of the constituent particles, the statistics obeyed by them and the laws of interaction towards each other. Hence, as in the earlier stages of study of many other branches of science, ad hoc hypotheses based on previous knowledge, have to be invented, and the value of these hypotheses is determined by the amount af success achieved by them. It now seems to be fairly certain as mentioned in the introduction that the nucleus consists of protons and neutrons only, and that there are no free electrons (or negative charge in any form) in the nucleus. Most of the protons are combined in the form of α-particles. From a scrutiny of Aston's mass-defect curves it has been deduced that elements after Pb are mostly built up by the addition of only α-particles to the Pb nucleus. Thus U (238/92) the parent of radio-active elements having $A = 4n + 2$ consists of a Pb nucleus (206/82) with 8 α-particles about it. Th (232/92) the parent of radioactive elements having $A = 4n$ consists of the lead nucleus (208/82) with 6 α-particles about it. The mass-defect curve shows that the binding force of these α-particles is very small, i.e., they can be regarded as free to a certain extent. They are prevented from leaving the nucleus by the existence of a potential barrier about the nucleus, whose height is larger than the energy of the α-particles in the crater. According to classical mechanics it will be impossible for the particles to leave the nucleus, but it was suggested by Gamow, and Gourney and Condon that according to wave-mechanics they can be regarded as waves, and thus possess the property of leaking through the barrier. The rate of leakage through the barrier determines the decay of the elements. Various hypotheses have been postulated regarding the height, size and form of the barrier, but the final results agree in their essential features. There is, however, a large amount of divergence in the methods of mathematisation of the ideas. Laue and others take simplified cases,[21] in which the process is regarded as stationary

and calculate the rate of leakage through an oblong-shaped potential barrier. Though the mathematics is much simplified, the picture does not evidently correspond to facts as the process cannot be ragarded as stationary (independent of time). Gamow,[22] on the other hand, introduces complex eigen-values, and by a suitable formulation of boundary conditions, obtains values of decay constants as well as of the eigen-values for the energy of the α-particles inside the crater. His final results are

$$\log \lambda = \log \frac{h}{4mr_0{}^2} - \frac{8\pi^2 e^2 (Z-2)}{hV_s M} + \frac{16\,\pi\,e\,m^{\frac{1}{2}}\,(Z-2)^{\frac{1}{2}}}{hM}\,r_0{}^{\frac{1}{2}}$$

$$E = \frac{n^2 h^2}{8mr^2} + U_0 = \tfrac{1}{2}\,m\,V_e{}^2$$

where $e$, $h$ and $Z$ have their usual meaning. M is the mass of the α-particle and $V_e$ is the velocity with which it escapes. $r_0$ is the "radius" of the product nucleus and $V_0$ mean potential energy of an α-particle inside it.

It is seen from the above formula that they involve two constants, viz., $r_0$ the equivalent radius of the crater, and $V_e$ the velocity of ejection of the α-particle. According to our picture, $r_0$ should not much vary for elements belonging to the same radioactive family while the radius $v_0$ is found to vary in a regular way from U to RaC and from Th to Th A. We get abnormally low values for it when we come to those interesting products RaC, ThC and AcC which disintegrate in a dual fashion, emitting both α- and β-rays. The value of $r_0$ falls from $8.3 \times 10^{-12}$ for RaA to $6.3 \times 10^{-12}$ for RaC; and from $8.1 \times 10^{-12}$ for ThA to $6.6 \times 10^{-12}$ for ThC.

We revert again to the question as to how the primary γ-ray referred to above which, by undergoing internal electrofission gives rise to the observed β-decay, is generated. It is reasonable to postulate that there are more than one potential barrier inside a nucleus, though their exact nature (i.e., their height and width) and forms can only be determined when we have a sufficient knowledge of the structural arrangement of the particles constituting the nucleus. Our assumption is that the primary γ-ray is generated by the leakage of an α-particle through an internal potential barrier, i.e., the α-particle leaks from one crater to another, both within the nucleus. It occupies a lower energy level in the new crater and the balance of energy constitutes the primary γ-ray. This primary γ-ray suffers an electrofission producing a positive and a negative electron. The positive electron attaches itself to one of the neutrons present inside the nucleus, thus raising the nuclear charge by unity. The negative electron is ejected, which constitutes the usual β-ray. The combination of the positron with the neutron will liberate some energy ( nearly equal to the difference between the masses of positron + neutron, and the proton) and this may account for the soft γ-rays that usually accompany a

β-disintegration. The life of the β-decay is determined by the rate of leakage of the α-particle from one inside crater to another and hence to the first order will be independent of the energy of the β-rays. Thus no simple relation (unlike the case of α-decay) is expected to exist between the maximum energy of β-rays and the life of β-decay, a conclusion which is more or less borne out by Sargent's curves.

On the above view it is to be expected that occasionally a positron may not be captured by the neutron, and it may emerge. The presence of positrons associated with the natural β-decay as suggested by Skobelzyn's experiments lends support to the views herein stated.

The explanation of the continuous energy distribution in the β-ray spectrum offers no special difficulties. In our case the energy of the primary γ-ray is shared between the positron and the electron, and so the energy of the electron can vary from zero to a maximum $(hv = \varepsilon + 2m_0c^2)$. The exact form of the distribution curve can only be calculated when we make additional assumptions regarding the mechanism of interaction. This will be examined on a future occasion.

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# ON THE DETERMINATION OF THE VALUES OF γ FOR AIR SATURATED WITH WATER VAPOUR AT VARIOUS TEMPERATURES.

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## Introduction

The value of γ is very important from the thermodynamical point of view, and a precise study of its variation has an important bearing on the molecular structure of gases and is of great help towards a better understanding of their dissociating equilibria. But the available data of high precision on γ is poor excepting for a limited number of gases and organic vapours. There is hardly any data for γ for air which is completely saturated with water vapour. In the present paper the author wants to report some results of his experiments on the determination of γ for air saturated with water vapour which were carried out at various temperatures ranging between about 15°C. and 80°C. The method used was to determine accurately the velocity of sound in saturated air at various temperatures by means of a resonating tube. This was done by setting up stationary waves in the tube by means of a telephone diaphragm, actuated by a source of constant frequency, *viz.*, a valve-maintained tuning fork oscillator, and measuring the internodal distance λ/2. The tube-velocity of sound in saturated air at any particular temperature was then obtained as a product of the wavelength, λ, and the frequency 'N' of the source. We can then obtain the value of γ, from the basic formula $V = \sqrt{\dfrac{P \cdot \gamma}{\rho}}$ .... (1) if the values of P and $\rho$ be known.

Recently C. D. Reid[1] has studied the increase in the velocity of sound due to the presence of moisture in air. He determined the velocity of sound at 20°C. in dry air, humid air (45% relative humidity) and in air completely saturated with water vapour (100% relative humidity) and by plotting this increase in the velocity of sound against the percentage relative humidity he has obtained a straight line graph satisfying the empirical relation, $V_H = V_0 + 0{\cdot}14\,H$ ... (2) where $V_H$ is the velocity at any relative humidity at 20°C.; $V_0$ is the velocity in dry air at 20°C. and H is the relative humidity. The author has also plotted the experimental values for a wide range of

temperature, of ($V_H - V_O$), the excess of the velocity of sound in saturated air over the velocity of sound in dry air at the same temperature, against the moisture content as well as against the temperature. These curves may be seen under section XIII.


## II

### Previous Experimental Methods and Discussion

The method of determining the velocity of sound in gases in resonating tubes is still considered by some to be not free from uncertain errors due to the tube-effects such as the dependence of tube-velocity, on the frequency, on the roughness of the wall surface, on its thickness and on the nature of the material of the tube, etc. But through the efforts of many observers in the recent time, specially G. W. C. Kaye[2] and G. G. Sherratt, who made precision measurements of the velocity of sound in different gases, contained in resonating tubes of different diameters and material, many of the uncertain tube-corrections have been totally removed, and for all practical purposes the validity of the Helmholtz-Kirchhoff expression has been firmly established. The divergence of results in connection with the tube-correction is mostly due to inaccurate and inconsistent experiments for which the theory cannot be blamed. This point is discussed fully later on.

On the other hand, the method of determining the velocity of sound in gases depending upon what is sometimes called Pierce's acoustical interferometer, making use of ultrasonic waves (generated either by the quartz crystal oscillator or by the magneto-striction oscillator) is free from all difficulties of tube-correction, on account of very high frequencies used, but involves other uncertain and irregular effects arising out of the diffraction phenomena (and impedance effect) which cause the velocity of sound to be higher than the accepted free-space value; the effect being considerable in case the measurements of wavelength are made when the source and the reflector are not very far from each other or when the frequency used is near about 42 kilocycles[3] per second. Further, the smallness of wavelengths measured (for instance at 60,500 cycles per second, the wavelength in air is only about 0·57 cm.) demand an extreme sharpness of maxima (or minima). But such sharpness of maxima, in practice, cannot be attained for obvious reasons that the positions of the maxima are ascertained from the deflection of the micro-ammeter needle, which even in the vicinity of a reaction, are not very steep. This point, however, may be illustrated from the careful experiments of Martin Grabau[4] who states that the accuracy of the setting of the mean position of a maximum is about 0·5 mm. for a frequency 19,790 cycles per

second (wavelength about 1·75 cms). Thus the ratio of the accuracy of setting to the wavelength observed is $\frac{0·5}{17·5}$ which is $\frac{1}{35}$. While in the present experiments (with the reasonating tube) to be described, the accuracy of the setting of the mean position of a maximum was within 0·5 mm. for a wavelength about 350 mms. and hence the ratio of the accuracy of setting to the wavelength is $\frac{1}{700}$. This may further be stressed by quoting the divergence of results which W. H. Pielemeier,[5] working carefully with a Pierce acoustical interferometer, obtained in the case of dry air. His values of the velocity of sound in dry air at 0°C. are as follows: 333· 3 m. per sec., 332 8 m. per sec., 334 5 m. per sec., 333·8 m. per sec. and 333· 7 m. per sec., which differ from each other to such an extent as to be practically of little use if one wishes to calculate the precise value of γ for dry air. These considerations* led the author to adopt the resonating tube-method for determining the internodal distances with a constant frequency source of sound, and it will be sufficiently proved in subsequent sections of this paper that it is possible to obtain the accurate values of the velocity of sound by the above method.

<div align="center">III</div>

### Description of the Apparatus

The apparatus consisted mainly of a movable source of sound mounted at an end of a brass rod which could move it throughout the entire length of the resonating tube; and a fixed reflector. No listening side-tube† was used but instead a microphone was placed just beyond the fixed reflector which was a thin disc of mica. A section of the main portion of the apparatus is shown in Fig. 1. AB is a straight pyrex glass tube (specially ordered for
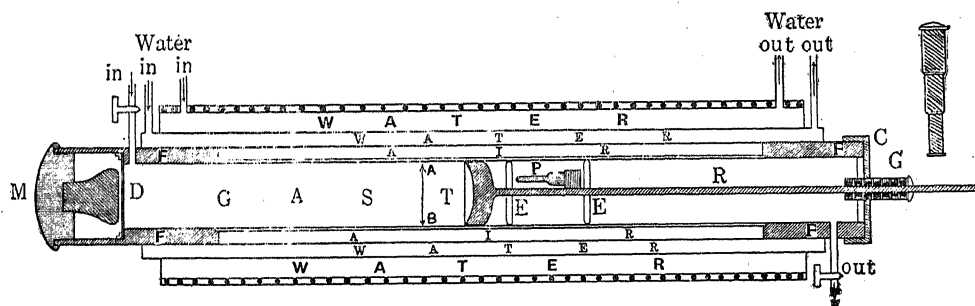


Fig. 1

these experiments) which is about 170 cms. long and 2 mms. thick with a nearly uniform bore of about 6·08 cms. diameter. FF are the brass flanges

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* Moreover, it is very difficult to maintain the oscillations of the quartz crystal in the presence of the large quantities of moisture contained in the saturated air and hence the accuracy of results is impaired.

† See discussion by Mr. D. A. Oliver, Proc. Phys. Soc., Vol. 43 ; 252 ; 1931.

fixed at each end of the resonating tube AB. Each flange in turn carries a side-tube of about 3 mms. diameter to serve as an inlet and an outlet for the gas under observation. D is a mica disc about 0'2 mm. thick which is mounted perpendicular to the axis of the tube by means of an arrangement of threaded brass rings which keep the mica disc rigidly fixed. The mica membrane D thus closes one end of the resonating tube and, as noticed before, serves the purpose of a reflector. This end of the tube, 'the reflector end,' to call it so, was made air-tight by means of plaster of paris. The other end of the resonating tube, the telephone end, is closed by means of a brass cap C at the extreme mouth of the flange F. In the centre of this cap there is an air-tight annular gland through which the brass rod R can be moved to and fro without any fear of leakage. The construction of the annular gland G is shown in Fig. 1 which is more or less like the flange arrangement used in piezometers of the usual type. The brass cap C at the end of the tube is also fitted with six terminals insulated from each other by means of mica and ebonite washers. Plaster of paris was used to make this end of the tube also air-tight, as far as possible. A telephone having a resistance of about 2000 ohms., and of such a size as to fit in the tube correctly, was mounted on the brass rod R so rigidly that there was no danger of any relative motion between the rod and the telephone diaphragm. Particular care was taken to keep the telephone diaphragm, perpendicular to the axis of the tube so that the reflector and the diaphragm of the telephone were always parallel to each other. In order to completely avoid the annular space left between the rim of the moving telephone and the wall of the tube, we wrapped round the rim a thin strip of flannel which acted like an elastic soft pad, so that this piston was a good fit in the resonating tube. The pad also served the purpose of eliminating all the undesirable creaking noises produced by the metallic telephone rim of the tube. To allow a more or less free passage of air past the rim of the telephone three small grooves were cut in the pad round the rim. Behind the telephone a perforated ebonite disc E of almost the same diameter as the telephone was mounted on the brass rod, which passed through its centre so rigidly that it moved along with the telephone throughout the tube. Immediately behind the ebonite disc E a platinum thermometer of length about 18 cms. and weighing about 105 grams was mounted by means of brass screws on the brass rod itself, and about 3'5 cms. away from the head of the platinum thermometer another perforated ebonite disc E was fastened rigidly on to the brass rod. Just beyond the mica reflector end of the resonating tube a small Lapel[6] microphone which was mounted on a circular wooden bed was fitted in such a way that the face of the microphone was about a centimetre away from the mica membrane. The circular wooden bed of the microphone fitted tightly in the brass flange F and thus kept the microphone fixed at that particular position. To match with this microphone

an audio-frequency transformer was used. Any sound received through the microphone was directly heard in the head-phones which were connected to the secondary of the transformer. The apparatus was placed on a V-shaped wooden platform.

<div align="center">IV</div>

## Sound Production and Remarks on the Constancy of the Frequency of the Source

The source of sound used in these experiments for setting up stationary waves inside the resonating tube was the telephone T electrically connected to the output terminals of a valve-maintained tuning fork oscillator such as that described by D. Dye.[7] The tuning fork used in the oscillator was made of 'elinvar' steel (Valentine and Carr) with a nominal frequency of about 1000 cycles per second. It was mounted very solidly in a solid block of brass which in turn was very rigidly riveted to a solid rectangular brass plate and the whole arrangement with the electrical attachments was placed in a small wooden box having a thick layer of soft woollen pad at its bottom. The same valve (Phillips A. 415) was used throughout all these experiments.

After making some preliminary experiments with sounds of different intensities in the resonating tube, we found it best to keep the anode voltage at 60 volts; the anode current in this case being of the order of 1·2 milliamperes. Voltages higher than this were deliberately not used in order to avoid sound waves of great intensity in the tube. To maintain the frequency constant, as far as possible, the oscillator was left completely undisturbed so that there was no danger of any change of frequency due to the causes, namely—(1) variation of filament current and anode voltage, (2) variation of grid and anode condensers, (3) variation of the polarising magnetic field, (4) variation of energy taken from the output winding, and (5) variation due to adding a mass to various parts of the mounting or to tilting of the fork.

The only cause of variation of frequency was the temperature of room which varied roughly between 28° C. and 36°C. But since the tuning-fork used is made of elinvar steel for which the temperature coefficient of frequency change is known to be very small, the change in the frequency for a range 28° C. to 36° C. may amount only to about 0·8 parts in ten thousands which being well within the experimental error was completely neglected. The frequency of the note under the actual conditions of the experiments (velocity experiments) as heard in the head phones was determined by comparing this with a certified tuning-fork also of elinvar steel (Valentine and Carr) having a frequency 1000 cycles per second when mounted solidly, as directed in the certificate. Beats were counted and the time was taken by means of a stop watch. This part of the experiment was extremely difficult because of the

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fact that the beats counted were very nearly six per second and hence extreme care had to be taken for accurate counting. However, many independent readings by different persons were taken to exactly fix the number of beats per second and the results of all such readings were found to be between 5·9 and 6·0 beats per second, so that the frequency of the note in the resonating tube under identical conditions of the actual velocity experiments comes to be (1000—6) =994 cycles per second. To test this point further and to facilitate the counting of beats accurately enough for our experimental purposes we loaded the prongs of the certified tuning-fork with equal quantities of soft wax placed symmetrically on both the prongs. The quantities of wax were at first so adjusted that absolutely no beat was observed. After this the quantities of wax on the prongs were halved and the beats produced under this condition were carefully counted. The mean of several such readings, for one experiment, was found to be 3·02 beats per second. Assuming a linear variation of beats with the added masses (wax) to the prongs (a fact approximately true for such a short range as this) we could conclude that the frequency of note in the resonating tube was (1000—3 × 2) =994 cycles per second, with a probable error of 0·1 per cent. It may be remarked here that the response of the ear to various frequencies is not the same. It is maximum near 1024—1028 cycles per second so that the choice of this frequency 994 was of great value in obtaining a high degree of accuracy in locating the points of maximum intensity of sound in the resonating tube. Another advantage in the selection of this frequency 994 is that the wavelength (in air about 35 cms.) is about 12 times the radius of the resonating tube (3·04 cms). Lord Rayleigh[8] pointed out that the waves set up in a cylindrical tube will ultimately become plane, provided the ratio of wavelength to the radius of the tube is greater than about 3·4. Sherratt and Awbery[9] have also experimentally found out this ratio to be 4·5 which is a little higher than the theoretical one (3·4). This ratio 12 in our experiments is thus far higher than even the experimental value 4·5 and hence all possibilities of the sound pattern in the resonating tube getting complicated by virtue of its natural transverse vibrations are eliminated so that there cannot be introduced any uncertain error due to this alone in the measurement of the internodal distances.

# V

## Temperature Control and Measurement

Since the temperature coefficient of change in the velocity of sound in air is about 0·6 metres per second, *i.e.,* it is of the order of 1 in 600, it is necessary that the temperature should be controlled and measured with an error not exceeding about 0·5°C. in order to attain a probable accuracy

of about 1 in 1000 in the measurement of the velocity of sound. Naturally in the construction of the apparatus we paid a great attention to those parts of the apparatus which controlled and measured the temperature. To achieve this, a double jacketted cylindrical vessel surrounding the entire length of the tube as shown in figure 1, was constructed. This vessel then was wrapped up in asbestos sheets and nichrome wire was wound round it to heat it electrically. In winding the wire care was taken to keep the spacing as far uniform as possible except at both the ends where the wire turns were a little denser than at the central portion of the vessel. The vessel was again wrapped up in thick sheets of asbestos so that the wire turns lay in between parallel layers of asbestos sheets. A set of variable resistances and an ammeter were placed in series to vary the current in the furnace according to need. In this arrangement the heating or cooling of the gas enclosed in the resonating tube was effected very gradually. This arrangement thus ensured uniformity and accurate regulation of temperature throughout the whole duration of the experiment (about three hours). But we had to wait long before the temperature became steady, in fact we had to wait for eight to ten hours; but once it became steady the outside fluctuation of temperature had very little effect on it.

Still there were three regions in the apparatus which lost heat through radiation and conduction. These were (1) the microphone end of the tube and a little portion, within two cms., of the brass flange which was not enclosed in the heating vessel, (2) the end G of the tube could not be enclosed in the heating vessel, and (3) the brass rod itself which, of necessity must make to and fro motion while the wavelength measurements were being made. The first two sources of heat loss were partly stopped by wrapping heavily the uncovered portions with cotton-wool (not shown in Fig. 1). The microphone and its wooden frame served very well to stop the heat flow through that end. The third source of heat loss for practical purposes was not serious as may be ascertained from the readings in table (1). Temperatures lower than the room temperature were obtained and maintained constant by passing a slow current of cold water through the two jackets of the surrounding vessel. The supply of this cold water was obtained from a small cistern kept about five feet higher than the level of the vessel. We made attempts to keep the temperature of the flowing water constant during the experiment, but the arrangement was not so satisfactory as in the case of heating. Temperatures were measured by means of a platinum resistance thermometer. Pure platinum wire of 0'15 mm. diameter was used. The wires were welded by electricity. Resistances were measured on a calibrated Callendar and Griffith's bridge. The sensitivity of the galvanometer used was $10^{-8}$ amperes per mm. deflection at a distance of one metre. Preliminary experiments were performed to determine the value of $\delta$ for the particular wire used.

The determination of the sulphur boiling point was however not very accurate. The mean value of $\delta$ found was 1'53. All precautions were taken to determine the fundamental interval accurately. The temperature with this arrangement could thus be ascertained accurately to about 0'05°C. To check the thermometer readings, we calibrated the platinum thermometer by directly comparing it with an accurate mercury thermometer reading up to $\frac{1}{10}$ of a degree C.

While taking observations for the wavelength determination, the readings of the platinum thermometer also were taken at each maximum. A typical set of readings is given below :—

*Table 1*

Room temperature 32°C.

| Order of maxima. | Resistance of pt. ther. in ohms. | Temp. in degrees C. |
|---|---|---|
| 1st max. ... | 3'0702 | 51'4 |
| 2nd „ ... | 3'0703 | 51'4 |
| 3rd „ ... | 3'0704 | 51'4 |
| 4th „ ... | 3'0703 | 51'4 |
| 5th „ ... | 3'0704 | 51'4 |

## VI

### The Measurement of the Distances between Successive Maxima

For the precise measurement of half wavelength it is clear that the distance between the successive maxima should be very accurately measured. An error of ±0'05 cms. for N = 1000, (half wavelength about 18 cms.) may vitiate the result by as much as 1 metre in the velocity and much more in the cases of higher frequencies. In order to avoid this source of error we measured the length by the comparator method making use of a travelling microscope which was very rigidly fixed on the same wooden V-bench on which the main apparatus was fixed. Great care was taken to avoid any relative motion between the microscope and the resonating tube by clamping both the tube and the microscope very rigidly. The microscope was clamped in such a position that it could be focussed on the brass rod very easily. Since the rod moved through grooves on wooden supports it always remained perfectly horizontal and so always in sharp focus for all positions of the travelling microscope. Very fine cross (×) scratches at intervals of about 10 cms. were made on the entire length of the brass rod in

such a way that they were all in a straight line on it.   The actual distances between the scratches were measured by the same travelling microscope. They are set down in table (2) below :—

### Table 2

#### Room temperature 32°C.

| Distances between scratches on rod. | | | Cms. | Distances between scratches on rod. | | | Cms. |
|---|---|---|---|---|---|---|---|
| 1st and 2nd | ... | ... | 11·06 | 7th and 8th | ... | ... | 10·02 |
| 2nd and 3rd | ... | ... | 10·03 | 8th and 9th | ... | ... | 10·07 |
| 3rd and 4th | ... | ... | 10·05 | 9th and 10th | ... | ... | 10·00 |
| 4th and 5th | ... | ... | 10·09 | 10th and 11th | ... | ... | 10·02 |
| 5th and 6th | ... | ... | 10·01 | 11th and 12th | ... | ... | 10·03 |
| 6th and 7th | ... | ... | 10·00 | | | | |

The temperature coefficient of the linear expansion for brass is about $18.9 \times 10^{-6}$ cms. and so the increase in length per degree between any two scratches (10 cms. length) would be $18.9 \times 10^{-5}$ cms.   Since that portion of the brass rod which was under the microscope was exposed to the outside atmosphere it was comparatively cooler than the resonating tube and hence its temperature did not much differ from that of the room.   Therefore the expansion in length between any two scratches on the rod would, in an extreme case, amount to only about $4 \times 10^{-3}$ cms. and hence it was completely neglected.   The effect of the sagging of the brass rod was also found to be quite negligible.   This was studied by direct measurement, by placing a calibrated steel scale lengthwise on the glass tube, (the furnace having been removed) and taking readings on the travelling microscope scale as well as on the steel scale simultaneously.   The scale of the travelling microscope was calibrated by comparing it with a standard platinum-irridium scale kept for this purpose in the laboratory.   The procedure of the measurement of the half wavelengths was as follows :—

A node was located by a proper adjustment of the position of the telephone inside the resonating tube and the microscope moved to one of the convenient scratches on the brass rod, which lay in the range of the travelling microscope scale and the scale reading was noted down, say, the second scratch on the brass rod coincided with the cross wires of the microscope when its position on the scale was 4·03 cms.   Then the rod R was slowly pulled out and the second node was located.   The microscope was then moved to some other convenient scratch and the scale reading taken, say, the third scratch coincides with the microscope reading 11·56 cms. From these readings we immediately get the distance between the first node and the second node as $(11.56 - 4.03) + 10.03$,

the distance between the second and the third scratch on the rod (table 2), which is equal to 17·56 cms. The same process was carried out for the rest of the nodes.

## VII

### The Location of Maxima

The points of maximum sound intensity, that is the nodes, being quite sharp, were easily detected. This was done, as follows, in two ways:—

(1) The brass rod carrying the telephone was moved slowly to a point of maximum intensity of sound which was audible only for a short range of
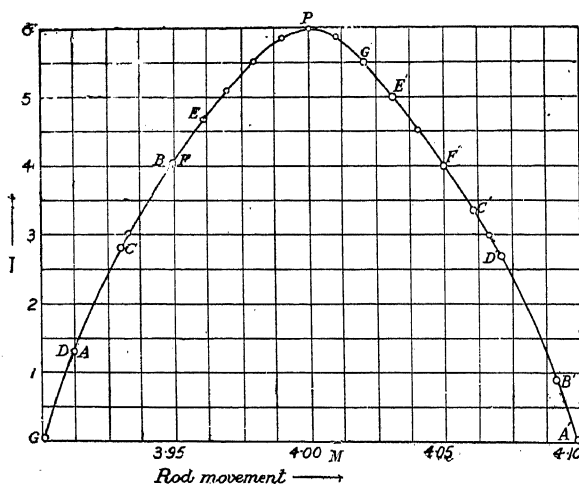


Fig. 2

the movement of the rod R (about 0·5 cm.) and two points were carefully marked, one while approaching the maximum and the other while receding from it, and the corresponding readings for these two points were taken on the travelling microscope scale. The mean of these two readings was then taken to indicate the correct position of the maximum on the assumption that the curve (Fig. 2), showing in an arbitrary way, the variation of intensity with distances of the rod movement, is symmetrical with respect to the perpendicular P.M. The difference between these two readings was seldom greater than about 1·5 mms. and was usually of the order of 1 mm. Several such pairs of readings were taken to locate a maximum. This process was repeated for every maximum. The whole process was then repeated by moving the rod in the opposite direction and the readings were obtained. For brevity this complete process may be called a run. To ascertain the consistency in the exact position of the maxima, several such runs were made, and the mean of all taken to calculate the final results.

These experiments were mostly carried out in perfect silence during the night with all the doors of the room closed. This not only facilitated the location of maxima, but also helped a good deal in keeping the temperature constant to a better degree than in the day-time when the air draughts disturbed it slightly.

(2) The second method of locating maxima was to attempt to locate the point P (Fig. 2) itself directly by a method of oscillation. This method requires a good deal of experience and practice and so is more

difficult than the first one, but all the same, it is more precise than (1). The difference of the reading (c) among themselves was of an order of 0˙5 mm. The mean of ten such readings when compared with the mean of five pairs of readings, taken as described under (1) differed from each other. The order of difference was about 0˙2 mm. But when the difference was found greater than this we placed more weight to the readings under (2) than those under (1). The following arbitrary curve (Fig. 2) which approximately represents the intensity of sound (as deduced from impression left on the memory) as the brass rod is moved in the vicinity of a maximum from one end to the other end situated symmetrically opposite to it, shows the accuracy of setting as well as the relative merits of methods (1) and (2) discussed above. The ends here do not mean exactly the limits between which the sound is audible; which in the case cited above would be about 5 or 6 mms. but by this we mean that we have to select two points such as A and A' of nearly equal intensity on either side of P and retain them in memory such that when the observations are repeated they may be located easily. These facts are illustrated from actual readings and may be considered as a typical example to clarify the principle of the method graphically, the readings below refer to the position of a maximum when the corresponding position of the second scratch on the brass rod, as read by the travelling microscope, was that given in table (3) below. The readings under (a) are the readings obtained while approaching the maximum and those under (b) taken while receding from it, and (c) are the readings obtained as described under method (2).

*Table 3*

| Points. | Readings (a) in cms. | Points. | Readings (b) in cms. | Mean of (a) and (b) in cms. | Readings (c) in cms. |
|---------|----------------------|---------|----------------------|-----------------------------|----------------------|
| A | 3˙91 | A' | 4˙10 | 4˙005 | 4˙02 |
| B | 3˙95 | B' | 4˙09 | 4˙020 | 4˙00 |
| C | 3˙93 | C' | 4˙06 | 3˙995 | 3˙98 |
| D | 3˙91 | D' | 4˙07 | 3˙990 | 4˙01 |
| E | 3˙96 | E' | 4˙03 | 3˙995 | 4˙02 |
| F | 3˙95 | F' | 4˙05 | 4˙000 | 4˙00 |
| G | 3˙90 | G' | 4˙02 | 3˙960 | 3˙99 |
| | | | | | 3˙98 |
| | | | | | 3˙99 |
| | | | | | 3˙97 |
| | | | | | 3˙98 |
| | | | | | 4˙01 |
| | | | | | 4˙02 |
| | | | | | 4˙01 |
| | | | | | 4˙00 |
| | | | | mean = 3˙999 | mean = 3˙991 |

From the curve (Fig. 2) the superiority of method (2) to method (1) is obvious, for it is likely to judge all points in (a) group as lying between, say, G and C and all points in the (b) group as lying between, say, P and F, thus tending to shift the mean value, P, to some such point as E. The error might become serious if the difference between the readings in an individual pair, be of the order of about 4 or 5 mms.

## VIII

### Filling the Resonating Tube with Air completely Saturated with Water Vapour

At first we tried this part of the experiment by simply blowing air through four wash bottles containing water and passing this air through the resonating tube for a few hours. The temperature of the fourth wash bottle, nearest to the gas inlet of the resonating tube was kept about five or six degrees higher than the actual temperature of the resonating tube, so that the final temperature of the saturated air, entering the resonating tube, was about the same as that of the air inside the resonating tube itself. In order to avoid the actual water particles entering the resonating tube, we placed wire meshes at several places in the path between the fourth wash bottle and the gas inlet. To ensure, that the air inside the resonating tube was at that temperature completely saturated with water vapour, some preliminary experiments were made. For this purpose, two special platinum thermometers, nearly identical to each other, were screwed, side by side, to the brass rod, R, and inserted in the resonating tube and the temperature of the air inside was thus read simultaneously by both the thermometers. Having done this, the bulb of one of the thermometers was covered with a piece of linen and a small glass tube, bent in nearly a semi-circular shape and closed at one end, to carry a little quantity of water, in order to keep the bulb of the thermometer wet, was fastened to the brass rod. The readings of the wet thermometer were found to be less than those of the dry thermometer by about one or two degrees, a fact which convincingly proved that the air thus saturated with water vapour by merely bubbling it through wash bottles containing water was not at all completely saturated. But at the same time, it was observed that the temperature of the wet thermometer was slowly rising, as time elapsed, so much so that after about an hour there was practically no difference in the readings of the wet and the dry thermometers. This showed us that the presence of water in the attached curved-tube and the wick of the thermometer, in a closed space like this, could slowly saturate the air completely in about less than an hour. It may be mentioned here that by quickly moving the brass rod, the temperature of the wet thermometer fell more than what it did when the brass rod was either stationary or very slowly

moved. In taking the wet and dry bulb readings the quick motion of the rod was avoided, so as to keep consistency with the usual convention of the dry and wet bulb hygrometry.[10] The importance of the necessity of a complete saturation of air in these experiments may be better realized by the actual experimental results given below.—

(a) The air was saturated by simply bubbling it through water and no water was introduced in the resonating tube. Under those conditions the velocity of sound in tube at 37·5° C. was found to be 355·54 m. per second.

(b) A little quantity of water was introduced at both the ends of the resonating tube and the readings were taken after about 15 minutes. The velocity of sound in this case was 356·28 m. per second.

(c) The third set of observations was taken after waiting for some time. The velocity in this case was 356·44 m. per second.

(d) The fourth set of observations was taken after a few minutes more. The velocity found was 356·43 m. per second.

(e) This set of observation was taken after waiting half an hour more. The velocity found was 356·38 m. per second.

These results show the process of saturation adopted in these experiments to be quite satisfactory. The process of saturating the air by mixing it thoroughly with steam and then filling the tube with the mixture was deliberately avoided for fear of the actual particles of water, in suspension in air, getting inside the resonating tube and creating other disturbances not desired.

## IX

### A Typical Set of Observations and Results

The temperature having been regulated and controlled, the resonating tube filled with the saturated air, as described, the internodal distances were located by hearing in the head phones and judging the points of maximum intensity of sound mostly by method (2) described under section VII. The observations were restricted only to the central portion of the tube about 100 cms. and a margin of about 35 cms. tube-length was left at each end of the tube. The arbitrarily chosen first maximum in table (4) was really the third node when counted from the mica membrane. The length of the tube was only 170 cms. and the internodal distance at about 75°C. was somewhat about 20 cms. and so only 5 maxima, at the most, could be located.

The pressure inside the resonating tube during the experiments was always kept equal to the atmospheric pressure which, however, was not constant, but the fluctuations in the atmospheric pressure, during a period of about three to four hours, were usually of an order of about two to four

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mms. mercury column. Therefore to get a mean value of the pressure it was read on a Fortin's barometer at least three times during a run which, as noticed before, lasted three to four hours. The mean of the three readings of the barometer was then taken to indicate the true pressure inside the resonating tube for any particular experiment.

The observations of a typical experiment are set down in table 4 (p. 283).

From the same set of observations in table (4) the velocity of sound was calculated in three different ways as follows : —

Method (A) : From table (4) and table (2), the distance between the 1st and the 3rd maximum

$$= [9{\cdot}180 - 3{\cdot}504] + [30{\cdot}17, \text{ which is the distance between the 2nd scratch}$$
$$\text{and the 5th scratch}]$$

$$= 5{\cdot}676 + 30{\cdot}170 = 35{\cdot}846 \text{ cms.} \qquad \qquad \text{(1)}$$

In the same way the distance between the 2nd and the 4th maximum

$$= [\text{the distance between the 3rd and the 7th scratch, which is } 40{\cdot}150] -$$
$$[11{\cdot}303 - 7{\cdot}088]$$

$$= 35{\cdot}925 \text{ cms.} \qquad \qquad \text{(2)}$$

Likewise the distance between the 3rd and the 5th maximum $= [$ the distance between the 5th and the 9th scratch which is $40{\cdot}150$ cms $]$
$$- [9{\cdot}174 - 5{\cdot}016]$$

$$= 35{\cdot}942 \text{ cms.} \qquad \qquad \text{(3)}$$

From these three values of $\lambda$, the mean wavelength is $35{\cdot}907$ cms.

The frequency of the source of sound $= 994$ cycles per sec.

∴ the velocity of sound in tube in saturated air at $37{\cdot}5°$C. is $356{\cdot}92$ m. per sec.

Method (B) : From table (4) and table (2), the distance between the 1st and the 5th maximum as before $= (5{\cdot}016 - 3{\cdot}504) + 70{\cdot}200$ and hence $\lambda = 35{\cdot}856$ cms. and the velocity in saturated air in tube at $37{\cdot}5°$C. $= 356{\cdot}41$ m. per sec.

Method (C) : The calculations of the velocity of sound by this method may be better realised by a glance at table (5) given below, which, in addition to other facts, shows that the experimental values of the internodal distances are never exactly equal to each other. This may be at first thought of as due to the error of observation itself, but the consistency of results, all in thorough agreement with the statement made above tends to show that this may be due to some real complexities other than the error of observation. In calculating the velocity of sound by method (C) these facts are considered by giving equal weight to all the observations and taking the mean value thus obtained to represent the true value of the velocity of sound in tube. The values

*Table 4*

| | 1st maximum 2nd scratch at | | | 2nd maximum 3rd scratch at | | | 3rd maximum 5th scratch at | | | 4th maximum 7th scratch at | | | 5th maximum 9th scratch at | | | Order of max. | Temp. deg. C |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Readings (a) cms. | Readings (b) cms. | Readings (c) cms. | Readings (a) cms. | Readings (b) cms. | Readings (c) cms. | Readings (a) cms. | Readings (b) cms. | Readings (c) cms. | Readings (a) cms. | Readings (b) cms. | Readings (c) cms. | Readings (a) cms. | Readings (b) cms. | Readings (c) cms. | | |
| | 3·45 | 3·56 | 3·49 | 11·22 | 11·34 | 11·28 | 9·23 | 9·14 | 9·18 | 7·14 | 7·04 | 7·07 | 5·10 | 4·95 | 5·00 | 1st max. | 37·5 |
| | 3·48 | 3·53 | 3·50 | 11·23 | 11·39 | 11·32 | 9·24 | 9·12 | 9·16 | 7·12 | 7·02 | 7·10 | 5·06 | 4·94 | 5·03 | | |
| | 3·43 | 3·54 | 3·52 | 11·26 | 11·38 | 11·30 | 9·22 | 9·13 | 9·18 | 7·15 | 7·05 | 7·09 | 5·07 | 4·96 | 5·01 | 2nd max. | 37·5 |
| | 3·46 | 3·52 | 3·50 | 11·24 | 11·35 | 11·29 | 9·24 | 9·15 | 9·18 | 7·12 | 7·04 | 7·08 | 5·08 | 4·93 | 5·01 | | |
| | 3·43 | 3·53 | 3·49 | 11·25 | 11·36 | 11·30 | 9·25 | 9·14 | 9·17 | 7·14 | 7·03 | 7·10 | 5·05 | 4·95 | 5·02 | 3rd max. | 37·5 |
| | 3·46 | 3·55 | 3·51 | 11·26 | 11·33 | 11·31 | 9·22 | 9·14 | 9·18 | 7·13 | 7·02 | 7·10 | 5·08 | 4·98 | 5·04 | | |
| | 3·42 | 3·57 | 3·52 | 11·24 | 11·35 | 11·32 | 9·24 | 9·13 | 9·18 | 7·13 | 7·04 | 7·09 | 5·07 | 4·97 | 5·03 | 4th max. | 37·5 |
| | 3·44 | 3·54 | 3·49 | 11·23 | 11·36 | 11·30 | 9·23 | 9·11 | 9·16 | 7·14 | 7·03 | 7·07 | 5·06 | 4·98 | 5·04 | | |
| | 3·47 | 3·55 | 3·48 | | | 11·30 | 9·21 | 9·14 | 9·17 | | | 7·08 | 5·08 | 4·97 | 5·00 | 5th max. | 37·5 |
| | 3·45 | 3·54 | 3·50 | | | 11·31 | 9·23 | 9·12 | 9·18 | | | 7·10 | | | 5·02 | | |
| | 3·45 | 3·57 | 3·52 | | | | | | | | | | | | 5·03 | | |
| | 3·48 | 3·58 | 3·51 | | | | | | | | | | | | 5·01 | | |
| | | | 3·49 | | | | | | | | | | | | 5·00 | | |
| | | | 3·49 | | | | | | | | | | | | 5·01 | | |
| | | | 3·51 | | | | | | | | | | | | 5·02 | | |
| | | | 3·52 | | | | | | | | | | | | 5·00 | | |
| | | | 3·52 | | | | | | | | | | | | 5·00 | | |
| | | | 3·51 | | | | | | | | | | | | | | |
| | mean of $\frac{a+b}{2}$ 3·501 | | mean of (c) 3·504 | mean of $\frac{a+b}{2}$ 11·299 | | mean of (c) 11·303 | mean of $\frac{a+b}{2}$ 9·180 | | mean of (c) 9·174 | mean of $\frac{a+b}{2}$ 7·084 | | mean of (c) 7·088 | mean of $\frac{a+b}{2}$ 5·010 | | mean of (c) 5·016 | | |

given in table (5) are taken from the same set of observations contained in table (4)

### Table 5

| The distance between | Cms. | λ/2 in each case. | V in each case m/sec. | Percentage difference in V from the mean in each case. |
|---|---|---|---|---|
| 1st and 2nd max. ...     ... | 17·829 | 17·829 | 354·44 | −0·560 |
| 1st and 3rd   „   ...     ... | 35·796 | 17·898 | 355·81 | −0·168 |
| 1st and 4th   „   ...     ... | 53·710 | 17·903 | 355·91 | −0·140 |
| 1st and 5th   „   ...     ... | 71·712 | 17·928 | 356·41 | −0·000 |
| 2nd and 3rd   „   ...     ... | 17·967 | 17·967 | 357·19 | +0·224 |
| 2nd and 4th   „   ...     ... | 35·881 | 17·941 | 356·67 | +0·056 |
| 2nd and 5th   „   ...     ... | 53·883 | 17·961 | 357·07 | +0·168 |
| 3rd and 4th   „   ...     ... | 17·914 | 17·914 | 356·13 | −0·084 |
| 3rd and 5th   „   ...     ... | 35·916 | 17·958 | 357·01 | +0·168 |
| 4th and 5th   „   ...     ... | 18·002 | 18·002 | 357·88 | +0·392 |
|  | mean | 17·930 | 356·45 |  |

Thus we see that the velocity of sound as calculated from the same set of observations but by different methods differ from each other, namely by methods

(a) V = 356·92 m/sec.

(b) V = 356·41 m/sec.

(c) V = 356·45 m/sec.
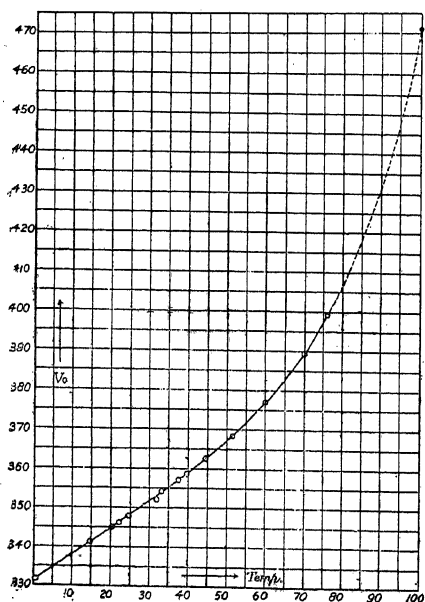
The final results of the velocity of sound given in table (6) and Fig. (3) have been calculated by method (C). The differences between the results calculated by (b) or (c) were negligible but those between the results calculated by (a) and (c) were of the order of 0·5m/sec. The accuracy of the results is claimed to be of the order of about 1 in 1000 up to the temperature about 60°C. The accuracy* of results above this temperature may be somewhat about 5 parts in 1000.



Fig. 3

* The accuracy of results above 60°C. is a little less because at such temperatures the maxima were not sharp, probably due to the large absorption of sound by the saturated air, which, for instance, at 60°C. contains about 130 grams of moisture per cubic metre.

### Table 6

| Temperature. | V m/sec. | Tube* correction. | $V_o$ m/sec. |
|---|---|---|---|
| 14·9°C | 340·87 | 0·52 | 341·39 |
| 20·3°C | 344·50 | 0·53 | 345·03 |
| 21·9°C | 345·54 | 0·53 | 346·07 |
| 24·6°C | 347·36 | 0·54 | 347·90 |
| 31·7°C | 352·29 | 0·55 | 352·84 |
| 33·1°C | 353·45 | 0·55 | 354·00 |
| 37·5°C | 356·49 | 0·56 | 357·05 |
| 39·5°C | 358·09 | 0·56 | 358·65 |
| 44·5°C | 362·03 | 0·57 | 362·60 |
| 51·4°C | 367·82 | 0·58 | 368·40 |
| 60·1°C | 376·63 | 0·59 | 377·22 |
| 69·7°C | 388·77 | 0·60 | 389·37 |
| 75·6 | 399·03 | 0·61 | 399·64 |
| (100°C)† | | | (471·5) |

## X

## The Tube Correction

Since the tube we have been using in our experiments has quite a smooth surface, we calculated the tube-correction by assuming the experimental value of Kirchhoff constant C to be correct for all practical purposes. Kaye and Sherratt,[2] after careful and extensive experimentation, of a high order of accuracy, have, concluded "that in general the Helmholtz-Kirchhoff equation is substantially valid for smooth tubes." Grüneisen and Merkel[11] who also agree with the form of the Helmholtz-Kirchhoff equation have obtained a value of C which is in accord with the value of C obtained by Kaye and Sherratt. These facts may be considered as sufficient to establish the validity of the much disputed expression

$$V = V_0 \left\{ 1 - \frac{C}{2\,r\,(\pi\,N)^{\frac{1}{2}}} \right\} \qquad \cdots \cdots \cdots \quad (3)$$

The mean values of C given by Kaye and Sherratt[2] for the case when dry air was used in glass tubes of smooth surface are 0·51 at 18°C. and 0·61 at 100°C.; the theoretical values of C for the same two temperatures being 0·56 and 0·69 respectively. The temperature range of our experiments extended from about 15°C. to about 80°C. Therefore in the present series of experiments there are also temperatures other than these two, namely, 18°C. and 100°C., thus rendering it necessary to know the values of C at these intermediate temperatures also. But the data for the experimental values of C at different temperatures ranging between 15°C. and 80°C. are at present not available; so that we thought it best to avoid this difficulty by an assumption

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* See Section X, table (8).
† W. G. Shilling, *Phil. Mag.*, Vol. 3, 293, 1927

(approximately true for a small range of temperatures as this) that the constant, C, varies linearly with the temperature and this enabled us to extrapolate the values of C for other temperatures. It may, however, be noted that the values of C given in table (8) are for the dry air and not for air saturated with water vapour as has been used in the author's experiments so that a correction may be needed in the values of C which according to theory is given by

$$C = \mu^{\frac{1}{2}} + \left(\frac{v}{\gamma}\right)^{\frac{1}{2}} (\gamma - 1) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

We can, however, calculate C for water vapour at different temperatures and densities by using the necessary constants and after taking a value of $\gamma$ for $H_2O$ which is typical for triatomic molecules. But we do not know what formula to adopt for C for a mixture of two gases. Hence we have taken C for pure dry air only. In the following table it is shown that even when gases of different composition are taken, C does not appreciably change.[*]

*Table 7*

| Gas | Air | $CO_2$ | $SO_2$ | $NH_3$ | $C_2 H_5 Cl.$ |
|---|---|---|---|---|---|
| At 18°C. C = | 0·51 | 0·31 | 0·26 | 0·41 | 0·64 |

Granting a change of even 20% in the value of C due to this cause (moisture) it can be shown that the error introduced by this assumption in the value of the free space velocity in our case is only of an order of about three to five parts in 10,000, which is well within the experimental error and hence can be altogether neglected without impairing the accuracy of the results.

The process of determining the tube-correction very accurately may be exemplified by two sets of experiments made to determine the tube-velocity of sound (1) in saturated air at 20°C., and (2) in air with relative humidity 64% at 28·5°C. The values obtained were:—

(1) V in saturated air at 20°C.=344·28 metres per second
(2) V in air with 64% relative humidity =349·21m. per second.

When these values of V together with the value of C (given in table 8) are substituted in equation (3) we at once get the tube correction. Thus:—

From (1) $$\frac{344 \cdot 28}{V_0} = 1 - \frac{0 \cdot 51}{2 \times 3 \cdot 04 \, (3 \cdot 14 \times 994)^{\frac{1}{2}}}$$

∴ $V_0$ at 20°C.=344·81.

Hence the tube-correction=$(V_0 - V)$
=(344·81 − 344·28)=0·53 m. per sec.

In the same way from (2), the tube-correction at 28·5°C. comes out to be equal to 0·54 m. per sec·

* Proc. Roy. Soc. A., Vol. 141 ; p. 139 ; 1933.

It may also be remarked here, by the way, that the tube*-correction calculated by the empirical formula[9] suggested by Awbery and Sherratt, namely,

$$\text{Percentage error} = \text{Constant} \times \lambda^{1 \cdot 5}$$

is in agreement with our results. The value of this constant comes out to be equal to 0·00077 and hence the tube correction at 20°C., is 0·52m. per second and at 50°C. it is 0·63 m. per second, and in our case, as noticed before, the values are 0·53 m. per second and 0·58 m. per second at 20°C., and 50°C., respectively. The following table (8) shows the value of C and the tube-correction at various temperatures.

### Table 8

| Temperature | C | Tube-correction |
|---|---|---|
| 20°C | 0·510 | 0·530 |
| 30°C | 0·523 | 0·544 |
| 40°C | 0·535 | 0·559 |
| 50°C | 0·547 | 0·575 |
| 60°C | 0·560 | 0·588 |
| 70°C | 0·572 | 0·599 |
| 80°C | 0·584 | 0·610 |
| 90°C | 0·597 | 0·621 |
| 100°C | 0·610 | 0·634 |

It may be interesting here to plot the tube-correction against the diameter of the tubes, for glass tubes (smooth surfaces) of three different
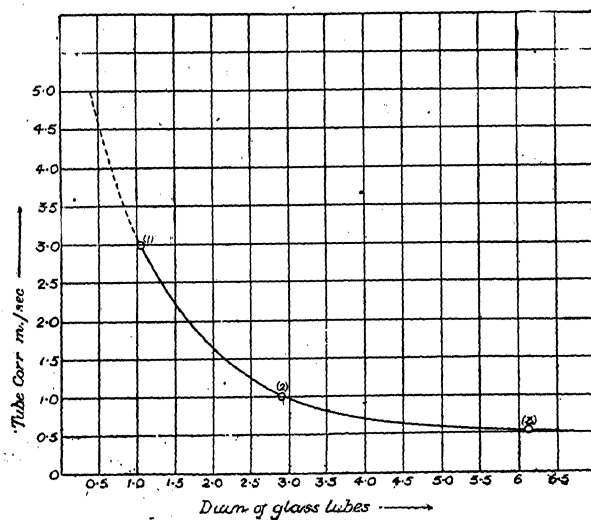


Fig. 4

diameter and for frequencies nearly 1000 cycles per second. Table (9) below contains the necessary experimental data used in this curve Fig. 4.

* The assumption here, too, made was that the expression is a function only of temperature and practically does not vary much with the varying moisture contents in the saturated air.

*Table 9*

| Diameter of glass tubes | Frequency | V m/Sec | V$_o$ m/Sec | Tube-correction | Temp. |
|---|---|---|---|---|---|
| *1·04 cms. | 988·5 | 339·4 | 342·4 | 3·00 | 18°C |
| *2·89 cms. | 988·5 | 341·4 | 342·4 | 1·00 | 18°C |
| 6·08 cms. | 994·0 | 344·29 | 344·83 | 0·53 | 20°C |

## XI
## The Calculation of Γ

In the calculation of Γ, the ratio of the two specific heats for saturated air, the free-space velocities of sound at various temperatures were obtained from the smooth curve Fig. 3 drawn on a very large squ red paper. No correction for the imperfection of the saturated air deviating from the ideal gas law was made but simply the equation

$$V = \sqrt{\frac{P\Gamma}{\rho}}$$ was used. $\rho_t$ the density

of the saturated air at t°C. was obtained by calculating $\rho_0$ the density of air at t°C. and the partial pressure (P—$p_{mt}$) and adding to this $\rho_m$, the density of the moisture present in the saturated air at t°C. Here P is the total pressure of the mixture (*i.e.*, saturated air) and $p_{mt}$ is the partial pressure of the moisture contained in the saturated air at t°C. The densities of the· moisture at various temperatures were calculated from Landolt's table, but more weight was given to the experimental values of the same obtained from a paper by J. H. Awbery (Proc. Phys. Soc., 44, 143, 1932).



Fig. 5



Fig. 6

The data for all such calculations and the results are given in table (10) below. Figs. (5) and (6) are the curves showing the variation of Γ with

* Kaye and Sherratt, *Proc. Roy. Soc* A., Vol. 141, p. 123, 1933.

Table 10

| Temp. | $V_0$ m/sec in saturated air. | Total press. P mms. | Partial press. of moisture $p_m$ mms. | Partial press. of dry air $p_D$ mms. | Density of dry air at press. $p_D$ i.e. $\rho_D$. | Calculated density of moisture $\rho_m$. | Experimental values of $\rho_m$ | Density of saturated air $\rho = (\rho_m + \rho_D)$ | γ for saturated air. |
|---|---|---|---|---|---|---|---|---|---|
| 15°C | 341·55 | 742·1 | 12·78 | 729·3 | $117·6 \times 10^{-5}$ | $1·2 \times 10^{-5}$ | ... | $118·8 \times 10^{-5}$ | 1·4009 |
| 20°C | 344·83 | 743·4 | 17·51 | 725·9 | $115·0 \times 10^{-5}$ | $1·8 \times 10^{-5}$ | ... | $116·8 \times 10^{-5}$ | 1·4008 |
| 25°C | 348·15 | 744·3 | 23·69 | 720·6 | $112·3 \times 10^{-5}$ | $2·309 \times 10^{-5}$ | $2·42 \times 10^{-5}$ | $114·7 \times 10^{-5}$ | 1·4007 |
| 30°C | 351·59 | 741·8 | 31·71 | 710·1 | $108·9 \times 10^{-5}$ | $3·041 \times 10^{-5}$ | $3·17 \times 10^{-5}$ | $112·1 \times 10^{-5}$ | 1·4005 |
| 35°C | 355·30 | 743·3 | 42·02 | 701·3 | $105·8 \times 10^{-5}$ | $3·964 \times 10^{-5}$ | $4·11 \times 10^{-5}$ | $109·9 \times 10^{-5}$ | 1·4000 |
| 40°C | 359·10 | 745·1 | 55·13 | 690·0 | $102·4 \times 10^{-5}$ | $5·118 \times 10^{-5}$ | $5·28 \times 10^{-5}$ | $107·7 \times 10^{-5}$ | 1·3989 |
| 45°C | 363·05 | 745·6 | 71·6 | 674·0 | $98·47 \times 10^{-5}$ | $6·544 \times 10^{-5}$ | $6·72 \times 10^{-5}$ | $105·2 \times 10^{-5}$ | 1·3949 |
| 50°C | 367·18 | 745·4 | 92·3 | 653·1 | $93·93 \times 10^{-5}$ | $8·299 \times 10^{-5}$ | $8·47 \times 10^{-5}$ | $102·4 \times 10^{-5}$ | 1·3893 |
| 55°C | 371·70 | 745·0 | 117·8 | 627·2 | $88·82 \times 10^{-5}$ | $10·433 \times 10^{-5}$ | $10·59 \times 10^{-5}$ | $99·41 \times 10^{-5}$ | 1·3828 |
| 60°C | 376·90 | 745·0 | 149·2 | 595·8 | $83·12 \times 10^{-5}$ | $13·011 \times 10^{-5}$ | $13·13 \times 10^{-5}$ | $96·25 \times 10^{-5}$ | 1·3765 |
| 65°C | 382·80 | 745·0 | 187·3 | 557·8 | $76·67 \times 10^{-5}$ | $16·116 \times 10^{-5}$ | $16·17 \times 10^{-5}$ | $92·84 \times 10^{-5}$ | 1·3697 |
| 70°C | 389·80 | 745·0 | 233·5 | 511·5 | $69·27 \times 10^{-5}$ | ... | $19·76 \times 10^{-5}$ | $89·02 \times 10^{-5}$ | 1·3618 |
| 75°C | 398·60 | 745·0 | 299·1 | 445·9 | $59·51 \times 10^{-5}$ | ... | $23·99 \times 10^{-5}$ | $83·49 \times 10^{-5}$ | |
| 80°C | 408·00 | 745·0 | 355·1 | 389·9 | $51·28 \times 10^{-5}$ | ... | $28·92 \times 10^{-5}$ | $79·7 \times 10^{-5}$ | |

F. 16

the temperature and with the moisture content of the saturated air at that temperature respectively.

## XII

### The Calculations of $\gamma_m$

In order to calculate the values of $\gamma_m$ for the moisture contained in the saturated air at different temperatures the values of $\gamma_D$ for dry air at these temperatures were obtained by taking the most probable experimental values of the velocity of sound in dry air at the same temperature. But the selection of these values was restricted to only such tube experiments in which due care was taken to make the apparatus really air-tight. The values of $\gamma_D$ for dry air were then calculated without applying any correction for the little deviation of dry air from the ideal gas law. The values of the velocity of sound in dry air taken from other workers together with the values of $\gamma_D$ for dry air determined by other experimental methods are also set down in table (11) below.

*Table 11*

| Temperature. | $V_o$ m/sec. | $\rho_D$ at 760 mms. pressure | $\gamma_D$ calculated. | Reference. |
|---|---|---|---|---|
| 0°C | 331·5 | $129·3 \times 10^{-5}$ | 1·4023 | Tube method, Kaye[2] and Sherratt. |
| 14°C | 339·8 | $123·0 \times 10^{-5}$ | 1·4016 | Tube method. |
| 18°C | 342·3 | $121·4 \times 10^{-5}$ | 1·4027 | Kaye[2] and Sherratt. |
| 100°C | 387·3 | $94·64 \times 10^{-5}$ | 1·4017 | ,,          ,, |
| 0°C | 331·44 | $129·28 \times 10^{-5}$ | 1·4017 | In free air, Hebb. |

| Temperature. | $\gamma_D$ corrected. | .. | $\gamma_D$ not corrected. | ... |
|---|---|---|---|---|
| 0°C | 1·4025 | .. | 1·4012 | Lummer and Pringsheim. |
| 0°C | 1·4003 | ... | 1·3992 | Moody. |
| 0°C | 1·4034 | ... | 1·4021 | Partington. |
| 0°C | 1·4029 | ... | 1·4016 | Shields. |
| 0°C | 1·4026 | .. | 1·4012 | Hebb (1904). |
| 0°C | 1·4031 | ... | 1·4017 | Hebb (1919). |

Having done this, we have calculated the values of $\gamma_m$, the ratio, of the two specific heats, for the moisture contained in saturated air at various temperatures by using Einstein's theoretical expression*:

$$\frac{P}{\Gamma - 1} = \frac{p_D}{\gamma_D - 1} + \frac{p_m}{\gamma_m - 1} \qquad . \qquad . \qquad . \qquad . \qquad (5)$$

The data for all such calculations and the results are given in table (12) below :

*Table 12*

| Temp 0°C. | Vap. pressure mms. | $p_m$ | $\Gamma$ | $\gamma_D$ | $\gamma_m$ |
|---|---|---|---|---|---|
| 15°C | 12·78 | $1·2 \times 10^{-5}$ | 1·4009 | 1·4021 | 1·3421 |
| 20°C | 17·51 | $1·8 \times 10^{-5}$ | 1·4008 | 1·4020 | 1·3568 |
| 25°C | 23·69 | $2·42 \times 10^{-5}$ | 1·4007 | 1·4019 | 1·3672 |
| 30°C | 31·71 | $3·17 \times 10^{-5}$ | 1·4005 | 1·4018 | 1·3736 |
| 35°C | 42·02 | $4·11 \times 10^{-5}$ | 1·4000 | 1·4018 | 1·3723 |
| 40°C | 55·13 | $5·28 \times 10^{-5}$ | 1·3989 | 1·4017 | 1·3671 |
| 45°C | 71·60 | $6·72 \times 10^{-5}$ | 1·3949 | 1·4017 | 1·3406 |
| 50°C | 92·30 | $8·47 \times 10^{-5}$ | 1·3893 | 1·4016 | 1·3199 |
| 55°C | 117·80 | $10·59 \times 10^{-5}$ | 1·3828 | 1·4016 | 1·3054 |
| 60°C | 149·2 | $13·13 \times 10^{-5}$ | 1·3765 | 1·4015 | 1·3015 |
| 65°C | 187·3 | $16·17 \times 10^{-5}$ | 1·3697 | 1·4014 | 1·2993 |
| 70·C | 233·5 | $19·76 \times 10^{-5}$ | 1·3618 | 1·4013 | 1·2976 |
| 75°C | 299·1 | $23·99 \times 10^{-5}$ | ... | ... | ... |
| 80°C | 355·1 | $28·92 \times 10^{-5}$ | ... | ... | ... |
| 85°C | 433·5 | $34·67 \times 10^{-5}$ | ... | ... | ... |
| 90°C | 525·8 | $41·28 \times 10^{-5}$ | ... | . | ... |

* It may however be noted that the expression

$$\frac{1}{\Gamma - 1} = \frac{\rho - \rho_D}{\rho_m - \rho_D} \cdot \frac{1}{\gamma_m - 1} + \frac{\rho_m - \rho}{\rho_m - \rho_D} \cdot \frac{1}{\gamma_D - 1}$$

due to Richarz (Ann. Phys. 1906) is the same as the expression (5).

The variation of $\gamma_m$ with temperature, with vapour pressure and with the moisture content is shown by the curves Fig. (7), Fig. (8) and Fig. (9) respectively. It may be interesting here to note a maximum* value of $\gamma_m$ occurring at the temperature about $32\cdot5°C$. or at the vapour pressure about 35 mms. or at the moisture content about $3\cdot5 \times 10^{-5}$ gms. per c.cm.



Fig. 7



Fig. 8

## XIII

It may be of interest to know the increase in the velocity of sound in air due to the moisture present in it. With this in view we have plotted $(V_H - V_D)$ against the temperature (Fig. 10) as well as against the moisture content (Fig. 11) for a wide range. Our result at $20°C$. is in agreement with that of C. D. Reid, but we do not think that the empirical relation (2) given in section 1 of this paper is strictly correct for cases when the moisture content in air is large. Table (13) contains the necessary data used in the above two curves (10) and (11).

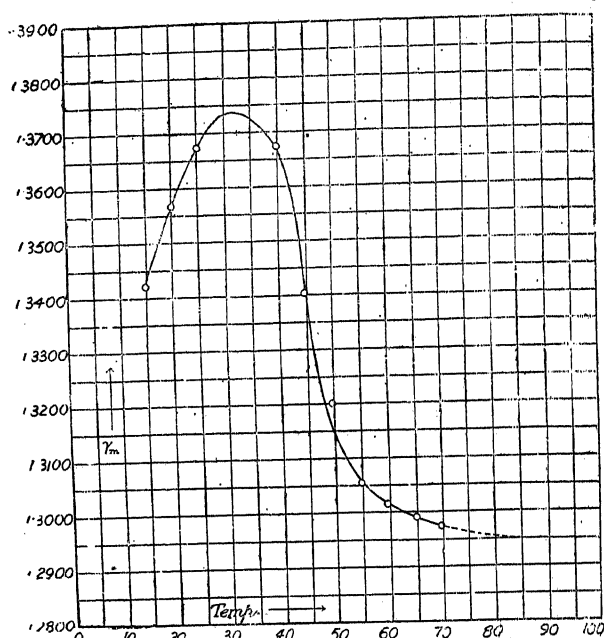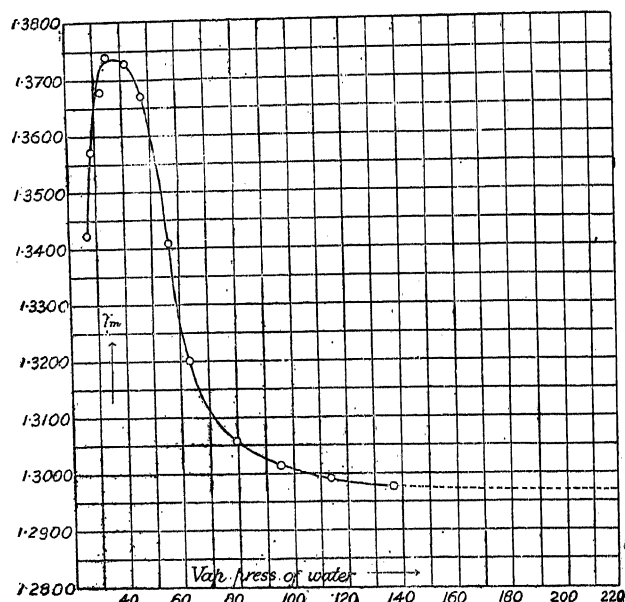* We are trying to investigate this problem further by still improving the apparatus and by taking more accurate readings with the saturated air at different temperatures ranging between about $25°C$. and $45°C$.
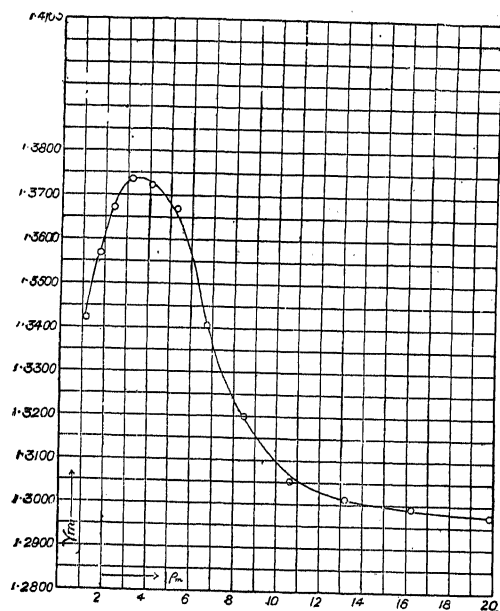
Fig. 9

Showing the variation of $\gamma_m$ with $\rho_m$.
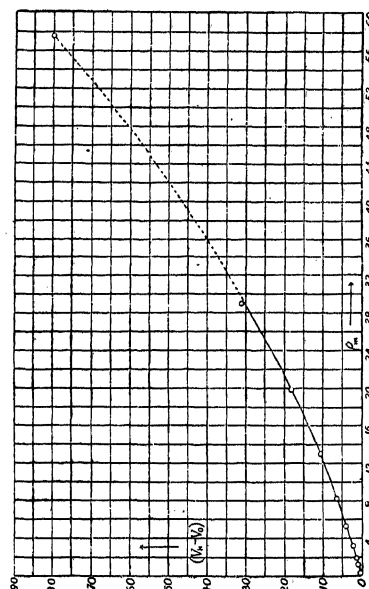
The value of the velocity of sound in steam at 100°C. is taken from W. G. Shilling, *Phil. Mag.* Vol. 3, 293, 1927.
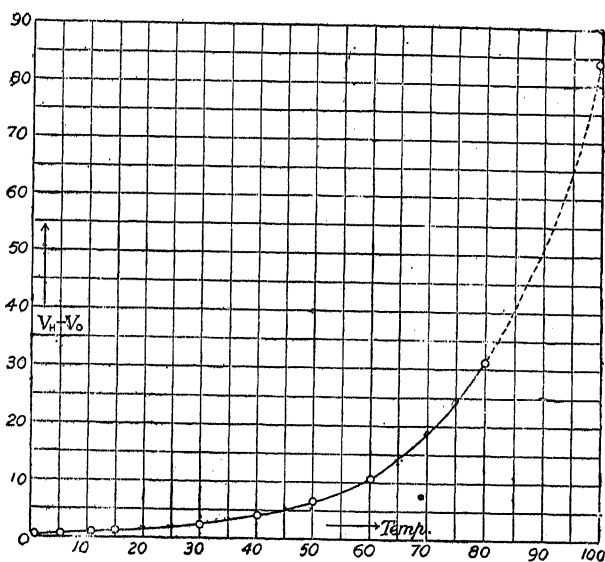


Fig. 10

*Table 13*

| Temperature | $V_H$, the free-space velocity in saturated air | $V_0$, the free-space velocity in dry air | $V_H - V_0$ m/sec. |
|---|---|---|---|
| 0°C | 331·60 | 331·50 | 0·1 |
| 10°C | ... | 337·6 | |
| 15°C | 341·55 | 340·40 | 1·15 |
| 20°C | 344·8 | 343·5 | ·32 |
| 25°C | 348·1 | 346·35 | 1·75 |
| 30°C | 351·5 | 349·3 | 2·2 |
| 35°C | 355·3 | 352·1 | 3·2 |
| 40°C | 359·1 | 354·95 | 4·15 |
| 45°C | 363·05 | 357·8 | 5·3 |
| 50°C | 367·2 | 360·7 | 6·5 |
| 55°C | 371·7 | 363·4 | 8·3 |
| 60°C | 376·9 | 366·2 | 10·7 |
| 65°C | 382·8 | 368·9 | 13·9 |
| 70°C | 389·8 | 371·6 | 18·2 |
| 75°C | 398·6 | 374·3 | 24·3 |
| 80°C | 408 | 377 | about 31 |
| ... | | | |
| (100°C) | (471·5)* | (387·3)† | (84·2) |

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* W. G. Shilling; Phil. Mag. Vol. 3; 293: 1927.

† G. W. C. Kaye and G. G. Sherratt; Proc. Roy. Soc. A 141; 123; 1933.

# CHEMICAL EXAMINATION OF THE SEEDS OF
## *ABRUS PRECATORIUS*, LINN. PART III.
## THE CONSTITUTION OF ABRINE

### By Narendranath Ghatak,

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In part I of this series of investigations[1] the seeds of the important medicinal plant *Abrus precatorius*, Linn. of the natural order Leguminosae, or Jequirity as it is known in English and Rati in Hindustani, were chemically examined. A colourless crystalline nitrogenous compound in the form of slender needles was isolated and named as 'abrine' which is most probably the active principle of the seeds. The pharmacological examination of the substance is in progress in the King George's Medical College, Lucknow. In the present paper it is intended to elucidate the constitution of abrine as far as it has been possible by the preparation of some of its derivatives.

Abrine is present in the kernels of the seeds of *Abrus precatorius*. In pure form it has no smell and is tasteless. It crystallizes in minute silky white needles from alcohol. In water it is sparingly soluble in the cold and crystallizes well from a boiling solution. If it is allowed to crystallize very slowly extending over several days, abrine is obtained in the form of stout, long crystals in the form of stars. Careful crystallization may increase the length of the crystals from two to three centimetres. It has a high melting point at 295°. When heated over flame in a dry test tube abrine melts, becomes brown with decomposition and gives out white fumes which have a very disagreeable odour. The fumes condense in the cooler parts of the tube forming a yellowish white liquid. When heated with zinc dust it gives out the same smell as above along with that of ammonia.

Abrine forms mono-hydrochloric and mono-nitric acid salts with the corresponding acids. It thus behaves as a mono-basic compound. Abrine does not produce any coloration with neutral ferric chloride solution but forms a mono-acetyl and mono-phenylurethane, proving thereby the presence of an alcoholic hydroxy group. The formation of a dibromo derivative with bromine proves the presence of a double bond in abrine. This is also borne out by volumetric estimation of unsaturation in abrine. Abrine forms a mono-nitroso derivative, thus showing the presence of a

secondary amino group. The facts that abrine does not respond to the *ninhydrin-reaction* and its aqueous solution is not coagulated by tannic acid show that it has no amino-acidic group in it. Abrine forms a mono-nitro derivative and is readily oxidised by solution of potassium permanganate.

## EXPERIMENTAL

It has already been shown[1] that the most suitable solvent for the extraction of abrine from the seeds of *Abrus precatorius* is alcohol, which takes out the substance in very small quantities. Solubility of abrine in water could not be used with advantage for its extraction as the powdered kernel of the seeds swells to a considerable extent in presence of water and working with such gelatinous mass becomes very difficult. The swelling is due to the presence of large quantities of albuminous and mucilagenous substances present in the kernels of the seeds.

For extraction of abrine, the hard yellow kernels were ground to a fine powder in a hand mill and was extracted in a big Soxhlet's extraction apparatus, with petroleum ether. When the oil was completely removed by the solvent the powder was freed from petroleum ether and exhaustively extracted with rectified spirit. With the progress of extractions the yellow colour of the powder became lighter and finally became white. The total alcoholic extract was concentrated to a small volume under reduced pressure. The thick brown syrup, which had a disagreeable odour, contained fine needle-shaped crystalline suspension. It was allowed to stand for about ten days when the quantity of the crystalline deposit increased. The product was separated and washed with benzene to remove oily contamination. It was next washed with small quantities of cold water which readily removed the sticky portions. The residue on crystallization from boiling water was obtained as fine silky white needles. As has previously been recorded, it has a molecular formula $C_{12}H_{14}O_2N_2$ and has been named "abrine". The general reactions of abrine have also been recorded. Its solution is not coagulated by tannic acid solution and is non-respondent to the *ninhydrin-reaction* of amino-acids.

## Abrine hydrochloride, $C_{12}H_{14}O_2N_2$. HCl

To 0·5 g. of abrine in a dry dish was added one c.c. of pure concentrated hydrochloric acid. Abrine immediately dissolved but very soon the whole of it was precipitated as white needle shaped crystals. The liquid contamination of the crystals was soaked out by means of filter papers. The product was dried in a vacuum desiccator over calcium oxide. It was then washed several times with dry ether to free it from traces of hydrochloric acid. It melted at 221·5° sharp. When slowly allowed to crystallize from fairly strong

hydrochloric acid, abrine hydrochloride separates in the form of long stout needles in starry clusters.

[Found: Cl=14·25 %; $C_{12}H_{15}O_2N_2$ Cl, requires Cl=13·94%.]

Abrine hydrochloride dissolves in water but soon after a flocculent white precipitate separates. On analysis the precipitate has been found to be pure abrine and the filtrate contains hydrochloric acid. The combination of abrine with hydrochloric acid is therefore fairly weak and their detachment is effected in presence of water.

## Abrine nitrate, $C_{12}H_{14}O_2N_2$. $HNO_3$

0·5 g. of abrine was put in a small clean beaker and very dilute nitric acid was added slowly till the whole of abrine just dissolved. Excess of acid was avoided. The solution was kept for spontaneous evaporation. After few days long white needles of abrine nitrate separated. The crystals were dried within filter papers and finally in a vacuum desiccator over calcium oxide. It was finally washed with dry ether and on drying melted at 143° with decomposition. Abrine nitrate is very soluble in water and the combination of the salt is very stable in presence of the solvent.

[Found: N=15·42%; $C_{12}H_{15}O_5N_3$, requires N=14·94 %.]

## Abrine picrate, $C_{12}H_{14}O_2N_2$. $C_6H_3O_7N_3$

1 g. of picric acid was dissolved in 30 c.c. of alcohol (98 %) and 0·5 g. of abrine was added. On slight warming, abrine dissolved and the colour of the solution slowly darkened and finally became orange-red. It was then heated to boil and allowed to stand overnight. Next morning orange-yellow crystalline plates in clusters were formed. The mother liquor was decanted off and the crystals were washed free from picric acid with dilute alcohol. The picrate weighed 0·9 g. and melted at 194° with decomposition. It was quite stable in presence of water in which it was very little soluble, forming faint yellow solution.

[Found: N=16·06 %; 15·92%; $C_{18}H_{17}O_9N_5$, requires N=15·66%].

The picrate was also prepared in glacial acetic acid from which two different types of crystals were obtained—(1) orange-red needles in form of stars, and (2) very closely packed soft yellow needles. Both melted at 194° with decomposition and the nitrogen content was 15·96 per cent and 15·89 per cent respectively. The orange-red variety changed colour and became perfectly yellow at 120°. Thus all the three varieties were mono-picric acid salts of abrine having only different crystalline modifications.

## Dibromo abrine, $C_{12}H_{14}O_2N_2Br_2$

0·5 g. of abrine was put in a dry flask and alcoholic solution of bromine was added in the cold. The colour of bromine was discharged and abrine

F. 17

dissolved forming a light pink solution. Excess of bromine solution was added and was left for spontaneous evaporation at room temperature. After few days soft yellow plates settled at the bottom and the mother liquor remained brown. Addition of water did not separate more of the bromo derivative. Some acetone was next added when the solid deposit became colourless and the brown mother liquor was decanted off. It was thus freed from bromine by two more washings with acetone. The product on drying was obtained as whitish microcrystalline powder. It slowly started turning dark from 220° and melted between 241-42°, with decomposition.

[Found Br.=42·7 %; $C_{12} H_{14} O_2 N_2 Br_2$, requires Br=42·3%.]

The volumetric estimation of unsaturation in abrine was carried out as follows:—0·2974 g. of abrine was dissolved in 10 c.c. of carbon tetrachloride in a stoppered 250 c.c. measuring flask and N/3-bromine (20 c.c.) in the same solvent added and the mixture allowed to stand in a dark place for 24 hours. The mixture was then cooled in ice and water (25 c.c.) quickly added and well shaken and then 10 per cent potassium iodide solution (25 c.c.) with water (75 c.c.) introduced and the whole thoroughly agitated. The iodine thus liberated was titrated against N/10 sodium thiosulphate. After titration, 2 per cent potassium iodate (5 c.c.) was added and the titration repeated. Twice this value was deducted from the above titration value and the equivalents of bromine atoms taken up by abrine molecule calculated, which came to 1·97. This means one double bond in abrine.

## Nitro-abrine, $C_{12} H_{13} O_2 N_2 . NO_2$

1 g. of abrine and 20 c.c. of nitric acid (d. 1·2) was put in a nitration flask. Abrine dissolved with evolution of heat and the colour of the solution became orange-red. In about an hour the whole of abrine was dissolved. It was refluxed for about 5 hours over water bath. On cooling a pasty brown mass settled at the bottom. The mother liquor on dilution with water deposited a flocculent yellow mass. The precipitate was washed, dried and crystallized from dilute alcohol. When heated, it shows no sign of melting, darkens at about 185° and finally decomposes at about 220°, being then a carbonaceous powder. The product was proved to be a nitro compound by silver deposit test (zinc, alcoholic silver nitrate and substance).

[Found N=16·3 %; $C_{12} H_{13} O_4 N_3$, requires N=16·0 %.]

## Nitroso-abrine, $C_{12} H_{13} O_2 N_2 . NO$

To a cooled solution of 0·5 g. of abrine in 20 c.c. of 10 per cent acetic acid was added a well cooled solution of 0·25 g. of sodium nitrite in 10 c.c. of water.

An yellow coloured precipitate was formed which was filtered. It was washed with 5 per cent acetic acid and then with water. It was dried in a vacuum desiccator when it melted at 121°.

[Found $N = 17.2\%$ ; $C_{12} H_{13} O_3 N_3$, requires $N = 17.0\%$.]

### Acetyl abrine, $C_{12} H_{13} ON_2 . O. COCH_3$

1 g. of abrine was refluxed with 10 c c. of acetic anhydride and fused sodium acetate for about an hour. It was cooled. On addition of cold water a brownish yellow paste separated, which solidified becoming brittle on long standing. It was twice crystallized from dilute alcohol and animal charcoal, when it was obtained as a white microcrystalline power. It melted at 286-287° with decomposition.

[Found $N = 10.9\%$ ; $C_{14} H_{16} O_3 N_2$, requires $N = 10.8\%$]

### Abrine-phenylurethane, $C_{12} H_{13} ON_2 . O. CO. NHC_6 H_5$

0.7 g. of abrine and 10 c.c of phenyl*iso*cyanate was kept in a dry flask and refluxed over water-bath, carefully avoiding the entry of water vapour into the flask. Abrine dissolved slowly and the colour of the mother liquor became yellow. On allowing the product to stand at ordinary temperature for some time the phenylurethane product crystallized out which was filtered off and washed with benzene till the smell of phenyl*iso*cyanate had completely disappeared. It was recrystallized from alcohol, when it was obtained as white needles. It melted at 271°.

[Found $N = 12.8\%$ ; $C_{19} H_{19} O_3 N_3$, requires $N = 12.5\%$.]

The author wishes to express his indebtedness to the " Lady Tata Memorial Trust " of Bombay for a scholarship which enabled him to take part in the investigation.

### *Reference*

1. Ghatak and Kaul, *J. Indian Chem. Soc.*, 9, 383, 1932.

# BUSINESS MATTERS

# Business Supplement

## ANNUAL MEETING

The Annual Meeting of the Academy of Sciences was held in the Vizia-nagram Hall, Muir College Buildings, Allahabad, at 4 p. m. on Saturday, January 20, 1934. The Hon'ble Sir Shah Sulaiman, Kt., M.A., LL.D., Chief Justice, High Court, Allahabad, presided over the function. Prof. A. C. Banerji, the General Secretary, read the Annual Report of the Academy of Sciences for 1933.

Dr. K. N. Bahl, D. Sc., D. Phil., the President of the Academy, read his address. The Hon'ble Sir Shah Sulaiman then delivered his speech.

Prof. N. R. Dhar proposed a vote of thanks to the Hon'ble Sir Shah Sulaiman and Dr. H. R. Mehra seconded the vote of thanks.

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# SECRETARIES' REPORT

We have the honour to submit the following report on the working of the Academy during the period beginning from the 1st of January, 1933, and ending on the 31st of December, 1933.

The Second Annual meeting of the Academy of Sciences was held in the Vizianagram Hall, Muir College Buildings, Allahabad, on Friday, January 13, 1933. The Hon'ble Mr. J. P. Srivastava, the Minister of Education, presided over the function. His Excellency Sir William Malcolm Hailey, the PATRON of the Academy, whose keen interest and affection for the Academy are well-known, sent an inspiring message of hope and encouragement to the members of the Academy.

The Academy is making steady progress and has acquired a definite status in the eyes of the Scientists in India and abroad. It has now on its roll 117 members of whom 27 are non-resident members. Dr. S. S. Bhatnagar of Lahore was elected a Fellow of the Academy. We are much indebted to Government for the non-recurring grant of Rs. 2,000 which we received during the current financial year.

We are glad to mention that the Bulletin of the Academy has at of the a high level of achievements and has been well received in the scientifi, decide

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We are now receiving in exchange 99 Foreign and Indian Journals as compared to 53 Journals last year. 'NATURE', the well-known scientific journal of Great Britain, remarks in its issue dated 23rd of September, 1933, "The original memoirs published in the issues of the Academy represent a high standard of achievements." As the number of original papers submitted to the Academy is steadily increasing, it has become necessary to increase the size of the Bulletin and if possible to publish six issues of the same in each year instead of four as at present. Moreover the necessity of publishing a popular scientific journal is keenly felt. We shall have also to organise a scientific library for the province. But we are unable to give effect to our ideas and extend the sphere of our useful activities with the present non-recurring grant of Rs. 2,000 per annum. We hope and trust that Government will place us under further obligation by sanctioning a recurring grant of Rs. 4,000 per annum.

We are also indebted to the University of Allahabad for a grant of Rs. 500 during the current year, and shall approach also the other Universities of these Provinces for suitable grants. The need for a building of the Academy is urgently felt, and an appeal for raising money for this purpose will soon be issued. We shall require a Lecture Hall, a Reading Room, a Library and an Office in this building.

The thanks of the Academy are due to the Hon'ble Minister of Education, U. P., for founding a Gold Medal to be awarded to the author of the best paper published in the Bulletin in any year. The rules for the award of the medal have been framed.

The Academy welcomed the proposal of its Council that the name of the Academy of Sciences, U. P., be changed to the Indian Academy of Sciences. Dr. M. N. Saha, as the General President of the Indian Science Congress, 1934, was asked to bring the above resolution to the notice of the Scientists, who assembled at Bombay, and to discuss the whole question with them.

The General Committee of the Indian Science Congress at Bombay decided in favour of founding an Indian Academy of Sciences, and a committee has been formed to frame the constitution of the above Academy, and to take necessary steps for bringing into existence. The Academy of Sciences, U. P., has been invited to send a representative to serve in this committee.

The Academy conveyed its respectful felicitations to His Excellency Sir William Malcolm Hailey, the Patron of the Academy, on the conferment of the degree of Doctor of Laws by the University of Allahabad, for his eminent services to the cause of scientific research and education.

Our thanks are due to Mr. Narendranath Ghatak, M.Sc., for kindly helping us in the publication of the Bulletin. We also wish to express our thanks other office-bearers and the members of the Council of the Academy for grudging help and active co-operation.

## ABSTRACTS OF THE PROCEEDINGS.

The list of the Office-Bearers and Members of the Council to which the management of the affairs of the Academy was entrusted for the year 1933-34 is given in appendix A.

Appendix B contains the list of names of 117 members who were on the roll of the Academy on March 31st, 1934.

The Council expressed its deep gratitude to the Government for the non-recurring grant of Rs. 2,000 awarded to the Academy for the year 1933-34.

It was resolved that provided the Government of the United Provinces have no objection, the name, "The Academy of Sciences of the United Provinces of Agra and Oudh" be changed to "The Indian Academy of Sciences."

The Council expressed its gratefulness to the Hon'ble Minister of Education, U. P., for founding a Gold Medal to be awarded to the author of the best paper published in the Bulletin in any year, and framed the following rules for its award:—

1. The medal will be awarded annually, provided in the opinion of the Council there is a candidate whose work is of sufficient merit.

2. The medal will be awarded in a particular year in one of the five groups of subjects mentioned below.

The group of subjects will be taken in rotation, provided that if no award is made in any particular year, the Council may award the medal for the group of the year in any subsequent year.

The following are the five groups of subjects :—

(i) Zoology and Medicine.
(ii) Mathematics and Astronomy.
(iii) Physics and Engineering.
(iv) Chemistry and Technology.
(v) Botany, Agriculture and Geology.

3. A person to whom a medal has been awarded once shall not be eligible for it a second time.

4. The medal shall be awarded on the basis of the merit of the paper published in the Bulletin or Journal of the U. P. Academy of Sciences, or in any other publication of the Academy.

5. The Council of the Academy shall ordinarily appoint three judges who must be experts in the subject to consider the award of the year.

Each judge shall submit his report separately and without consulting the other judges to the Council in a sealed cover marked "Confidential."

The President of the Council or in his absence the Vice-President or a Secretary shall open the covers in the presence of the members of the Council. The Council shall, after considering the reports of the judges, decide

upon the relative merits of the candidates for the medal and resolve upon the person to whom the medal should be awarded. If in the opinion of the Council no candidate deserves the award of the medal, it may withhold the award of the same.

While considering the reports of the Judges, the Council may, if it so desires, take into consideration at its own initiative any other work published by the Academy even the author of such a work has not submitted it for the award of the medal.

6. The Secretary will invite the authors to submit their papers for the medal by the end of July each year. The Council shall appoint the judges in August and the Secretary will submit the papers to them by the middle of September. The judges shall submit their reports by the end of October, and the Council shall decide the award at its Annual Meeting in November. The medal will be presented to the successful competitor in the Anniversary Meeting, and a statement of the grounds on which the award has been made will be made by the President.

7. A member of the Council so long as he remains a member, will not be eligible for the medal.

8. Only Members and Associates will be eligible for the medal.

9. No award shall be made merely on the basis of joint paper, but joint paper may be taken into consideration by the judges in considering the award.

10. In any matter not provided for here considering the award of the medal, the decision of the Council shall be final.

The following one member was elected Fellow of the Academy in the Fellow's meeting held on November 8, 1933 :.

1. Dr. S. S. Bhatnagar, D.Sc., Professor of Chemistry, Government College, Lahore.

The following members were elected Office-Bearers and the Members of the Council for the year 1934 in the Annual Meeting held on January 20, 1934:

## President :

1. Prof. K. N. Bahl, D. Sc., D.Phil.

## Vice-Presidents :

2. Prof. M. N. Saha, D.Sc., F.R.S., F.A.S.B., F.Inst.P., P.R.S.
3. Prof. B. Sahni, D.Sc., Sc. D., F.L.S., F.A.S.B.

## Honorary Treasurer :

4. Prof. D. R. Bhattacharya, M.Sc., Ph.D., D.Sc., F.Z.S.

## General Secretaries:

5. Prof. P. S. MacMahon, B.Sc., M.Sc., F.I.C.
6. Prof. A. C. Banerji, M.A., M.Sc., F.R.A.S., I.E.S.

## Foreign Secretary :

7. Prof. N. R. Dhar, D.Sc., F.I.C., I.E.S.

## Other Members of the Council :

8. Prof. Nihal Karan Sethi, D.Sc.
9. Dr. S. S. Nehru, M.A., Ph.D., I.C.S., M.L.C.
10. Prof. C. A. King, B.Sc., A.R.C. Sc., M.I.M.E.
11. Prof. Ch. Wali Mohammad, M.A., Ph.D., I.E.S.
12. Dr. H. R. Mehra, Ph.D.
13. Prof. Rudolf Samuel, Ph.D.
14. Dr. S. M. Sane, B.Sc., Ph.D.
15. Prof. C. Maya Das, B.Sc., M.A., I.A.S.
16. Prof. K. C. Pandya, D.Sc.

# APPENDIX A

## LIST OF OFFICE-BEARERS AND MEMBERS OF THE COUNCIL
### 1933

### President :

1. Prof. K. N. Bahl, D.Sc , D. Phil.

### Vice-Presidents :

2. Prof. M. N. Saha, D.Sc., F.R.S., F.A.S.B., F. Inst. P., P.R.S.
3. Prof. B. Sahni, D.Sc., Sc.D., F.L S., F.A.S.B.

### Hony. Treasurer :

4. Prof. D. R. Bhattacharya, M.Sc., Ph.D., D.Sc., F.Z.S.

### General Secretaries :

5. Prof. P. S. MacMahon, B.Sc., M.Sc., F.I.C.
6. Prof. A. C. Banerji, M.A., M.Sc., F.R.A.S., I.E.S.

### Foreign Secretary :

7. Prof. N. R. Dhar, D.Sc., F.I.C., I.E.S.

### Other Members of the Council:

8. Prof. K. C. Mehta, Ph.D., M.Sc.
9. Dr. S. S. Nehru, M.A., Ph.D., I.C.S., M.L.C.
10. Prof. Ch. Wali-Mohammad, M.A., Ph.D., I.E S.
11. Prof. K. K. Mathur, B.Sc., A.R.S.M.
12. Dr. P.L. Srivastava, M.A., D. Phil.
13. Prof. Robert F. Hunter, D.Sc., Ph.D.
14. Dr. S. M. Sane, B.Sc., Ph.D.
15. Prof. C. Maya Das, B.Sc., M.A., I.A.S.
16. Prof. K. C. Pandya, D.Sc.

## ORDINARY MEMBERS

R—Resident.   N —Non-Resident.

*—Denotes a Fellow.

Alphabetical List of Ordinary Members

| Date of Election. | | |
|---|---|---|
| 17-4-1931 | R | Asundi, (R.K.), Ph.D., Reader, Physics Department, Muslim University, Aligarh. |
| 21-12-1931 | N | Bagchi, (S.C.), B.A., LL.D., Principal, Law College, Calcutta. |
| 1-1-1930 | R* | Bahl, (K.N.), D. Phil., D.Sc., Professor of Zoology, Lucknow University, Lucknow. |
| 1-1-1930 | R* | Banerji, (A.C.), M.A., M.Sc., F.R.A.S, I.E.S., Professor of Mathematics, Allahabad University, Allahabad. |
| 29-2-1932 | R | Banerji, (G.N.), The Scientific Instrument Company Ltd, Albert Road, Allahabad. |
| 22-12-1932 | N | Banerji, (S.K.), D.Sc., Meteorological Office, Ganeshkhind Road, Poona 5. |
| 17-4-1931 | N | Basu, Saradindu, M.Sc., Meteorologist, Ganeshkhind Road, Poona 5. |
| 19-3-1931 | R | Bhargava, Saligram, M.Sc., Reader, Physics Department, Allahabad University, Allahabad. |
| 17-4-1931 | R | Bhargava, Vashishta, M.Sc., I.C.S., Assistant Magistrate and Collector, Budaun. |
| 17-4-1931 | R˙ | Bhatia, (K.B.), I.C.S., Joint Magistrate, Shahjahanpur. |
| 21-4-1933 | N* | Bhatnagar, (S.S.), D.Sc., Professor of Chemistry, Government College, Lahore. |
| 1-1-1931 | R* | Bhattacharya, (D.R.), M.Sc., Ph.D., Docteur ès Sciences, Professor of Zoology, Allahabad University, Allahabad. |
| 17-4-1931 | R | Bhattacharya, (D.P.), M.Sc., Bareilly College, Bareilly. |
| 3-4-1933 | R | Chand, Tara, M.A., D. Phil., Principal, K. P. University College, Allahabad. |
| 29-2-1932 | R | Charan, Shyama, M.A., M.Sc., Agra College, Agra. |
| 1-1-1930 | R* | Chatterji, (G.), M.Sc., Meteorologist, Upper Air Observatory, Agra. |
| 17-4-1931 | R | Chatterji, (K.P.), M.Sc., A.I.C., F.C.S., Reader, Chemistry Department, Allahabad University, Allahabad. |
| 17-4-1931 | R | Chatterji, (A.C.), D.Sc., Chemistry Department, Lucknow University, Lucknow. |

F. 2

| Date of Election. | | Alphabetical List of Ordinary Members |
|---|---|---|
| 15-9-1931 | R | Gordon, (C.B.), B.A., Christ Church College, Cawnpore. |
| 17-4-1931 | R | Gupta, (B.M.), D.Sc., Deputy Public Analyst to Government, United Provinces, Lucknow. |
| 21-12-1931 | R | Hansen, (W.J.), M.A., Allahabad Agricultural Institute, Naini, E.I.R., Allahabad. |
| 17-4-1931 | R | Higginbottom, Sam, D. Phil., Principal, Allahabad Agricultural Institute, Naini, E.I.R., Allahabad. |
| 17-4-1931 | R* | Hunter, Robert (F ), D.Sc., Ph.D., Professor of Chemistry, Muslim University, Aligarh. |
| 21-12-1931 | R | Joshi, (S.S.), D.Sc., Professor of Chemistry, Benares Hindu University, Benares. |
| 15-9-1931 | N | Kichlu, (P.K.), D.Sc., Department of Physics, Government College, Lahore. |
| 1-1-1930 | R* | King, (C.A.), B.Sc. (Hons.), A.R.C.Sc., M.I.M.E., Principal, Engineering College, Benares Hindu University, Benares. |
| 21-4-1933 | N | Kishen, Jai, M.Sc., Professor of Physics, S.D. College, Lahore. |
| 17-4-1931 | R | Koshambi, (D.D.), M.A., Department of Mathematics, Muslim University, Aligarh. |
| 9-2-1934 | N | Kothari, (D.S.), M.Sc., Ph.D., Professor of Physics, The University, Delhi. |
| 5-10-1933 | R | Kureishy, (A.M.), M.A., Reader in Mathematics, Muslim University, Aligarh. |
| 1-1-1930 | R* | Luxmi Narayan, D.Sc., Reader, Mathematics Deparment, Lucknow University, Lucknow. |
| 1-1-1930 | R* | MacMahon, (P.S.), B.Sc. (Hons.), M.Sc., Professor of Chemistry, Lucknow University, Lucknow. |
| 1-1-1930 | R* | Mathur, (K.K.), B.Sc. (Hons.), A.R.S.M., Professor of Geology, Benares Hindu University, Benares. |
| 1-1-1930 | R* | Mehta, (K.C.), Ph.D., M.Sc., Agra College, Agra. |
| 1-1-1930 | R* | Mitter, (J.H.), M.Sc., Ph.D., Professor of Botany, Allahabad University, Allahabad. |
| 15-9-1931 | R | Mathur, (L.P.), M.Sc., St. John's College, Agra. |
| 8-11-1933 | N | Mathur, Ram Behari, M.Sc., Professor of Mathematics, St. Stephen's College, Delhi. |
| 19-3-1931 | R | Mazumdar, Kanakendu, D.Sc., Physics Department, Allahabad University, Allahabad. |
| 19-3-1931 | R* | Mehra, (H.R.), Ph.D., Reader, Zoology Department, Allahabad University, Allahabad. |
| 21-12-1931 | R | Mehta, (N.C), I.C.S., Director of Agriculture, United Provinces, Lucknow. |

| Date of Election. | | Alphabetical List of Ordinary Members |
|---|---|---|
| 21-4-1933 | N | Mela Ram, M.Sc., Asst. Professor of Physics, Foreman Christian College, Lahore. |
| 21-4-1933 | R | Mukerjee, (A.C.), M.A., Philosophy Department, Allahabad University, Allahabad. |
| 21-4-1933 | N | Mukerjee, Ashutosh, M.A., Professor of Physics, Science College, P. O. Bankipore (Patna.) |
| 17-4-1931 | R | Mukerjee, (S.K.), M.Sc., Agra College, Agra. |
| 17-4-1931 | R | Mukerjee, (S.K.), D.Sc., Reader, Botany Department, Lucknow University, Lucknow. |
| 19-12-1933 | R | Naithani, (S.P.), M.Sc., Botany Department, Allahabad University, Allahabad. |
| | R | Narliker, (V. V.), M.A., Professor of Mathematics, Benares Hindu University, Benares. |
| 17-4-1931 | R | Nehru, (S. S.), M.A., Ph.D., I.C.S., M.L.C., Deputy Secretary to Government, U.P., Publicity Department, Lucknow. |
| 17-4-1931 | R | Panday, (K.C.), D.Sc., St. John's College, Agra. |
| 3-4-1933 | N | Parija, (P. K.), M.A., I.E.S., Ravenshaw College, Cuttack. |
| 5-10-1933 | R | Prasad, Gorakh, D.Sc., Reader in Mathematics, Allahabad University, Allahabad. |
| 21-4-1933 | N | Prasad, Kamta, M.A., M.Sc., Professor of Physics, Science College, P.O. Bankipore (Patna). |
| 15-9-1931 | N | Prasad, Mata, D.Sc., Royal Institute of Science, Bombay. |
| 3-4-1933 | R | Prasad, Badrinath, Ph.D., Docteur ès Sciences, Mathematics Department, Allahabad University, Allahabad. |
| 17-4-1931 | R | Puri, (B.D), M. A., Thomason Civil Engineering College, Roorkee. |
| 22-12-1932 | N | Qureshi, (M.), M.Sc., Ph.D., Professor of Chemistry, Osmania University College, Hyderabad, Deccan. |
| 3-4-1933 | R | Raja Ram, M.A., B.E., Principal of Civil Engineering, Thomason College, Roorkee, U.P. |
| 19-3-1931 | R | Ranjan, Shri, M.Sc., Docteur ès Sciences, Reader, Botany Department, Allahabad University, Allahabad. |
| 15-9-1931 | N | Rao, A. Subba, D.Sc., Medical College, Mysore |
| 22-2-1933 | N | Rao, G. Gopala, B.A., M.Sc., Chemistry Department, Andhra University, Waltair. |
| 21-12-1931 | R | Rao, D. H. Ramchandra, B.E., A.M.I.E., Engineer, Allahabad University, Allahabad. |
| 22-2-1933 | N | Ray, Bidhubhusan, D.Sc., 92 Upper Circular Road, Calcutta. |
| 21-12-1931 | R | Ray, Satyendra Nath, M.Sc., Physics Department, Lucknow University, Lucknow. |

| Date of Election | | Alphabetical List of Ordinary Members |
|---|---|---|
| 1-1-1930 | R* | Richards, (P.B)., A.R.C.S., F.E.S., Entomologist to the Government, United Provinces, Cawnpore. |
| 1-1-1930 | R* | Saha, (M. N.), D.Sc., F.R.S., F.A.S.B., F. Inst. P., P.R.S., Professor of Physics, Allahabad University, Allahabad. |
| 29-2-1932 | R | Saha, Jogendra Mohan, M.Sc., Manager, Srikrishna Desi Sugar Works, Jhusi, (Allahabad). |
| 1-1-1930 | R* | Sahni, (B.), D.Sc., Sc.D., F.L.S., F.A.S.B., Professor of Botany, Lucknow University, Lucknow. |
| 17-4-1931 | R* | Samuel, Rudolf, Ph.D., Professor of Physics, Muslim University, Aligarh. |
| 17-4-1931 | R | Sane, (S.M.), B.Sc., Ph.D., Reader, Chemistry Departmer cs, ...ity Badshah Bagh, Lucknow. |
| 21-12-1931 | R | Sathe, (J.L.), I.C.S., Fina... No. 1, Secretariat Quarters, Lucknow. |
| 3-4-1933 | R | Sen, (K. C.), D.Sc., Imperial Institute of Veterinary Research, Muktesar, Kumaun. |
| 21-4-1933 | N | Seth (J.B.), M.A., Government College, Lahore. |
| 17-4-1931 | R | Seth, (S.D.), M.Sc., Christ Church College, Cawnpore. |
| 1-1-1930 | R* | Sethi, (R.L.), M.Sc., M.R.A.S., Economic Botanist to Government, United Provinces, Cawnpore. |
| 19-3-1931 | R | Sethi, Nihal Karan, D.Sc., Agra College, Agra. |
| 15-9-1931 | R | Sharma, Ram Kishore, M.Sc., Physics Department, Ewing Christian College, Allahabad. |
| 3-4-1933 | N | Siddiqi, (M.R.), Ph D. Professor of Mathematics, Osmania University, Hyderabad, Deccan. |
| 3-4-1933 | R | Siddiqui, Mohd. Abdul Hamid, M. B. B. S., M. S , F. R. C. S., D. L. O., Professor of Anatomy, King George's Medical College, Lucknow. |
| 17-4-1931 | R | Singh, Avadesh Narain, D.Sc., Department of Mathematics, Lucknow University, Lucknow. |
| 17-4-1931 | N | Soonawala, (M.F.), M.Sc, Maharaja's College, Jaipur (Rajputana). |
| 19-3-1931 | R* | Srivastava, (P.L.), M.A., D.Phil., Reader, Mathematics Department, Allahabad University, Allahabad. |
| 10-8-1933 | R | Srivastava, (R. C), B.Sc., (Tech.) Sugar Technologist, Imperial Council of Agricultural Research, India, Cawnpore. |
| 15-9-1931 | N | Srikantia, (C.), B.A , D.Sc., Medical College, Mysore. |
| 19-12-1933 | R | Strang, (J.A ), M.A., B.Sc., Professor of Mathematics, Lucknow University, Badshah Bagh, Lucknow. |

| Date of Election | | Alphabetical List of Ordinary Members |
|---|---|---|
| 24-1-1933 | N | Subramanian, (S.), M.A., Mathematics Department, Annamalai University, Annamalainagar P. O., South India. |
| 17-4-1931 | R | Sulaiman, (S.M.), Hon'ble Sir, Chief Justice, High Court, Allahabad. |
| 19-3-1931 | R | Taimini, Iqbal Kishen, Ph.D., Chemistry Department, Allahabad University, Allahabad. |
| 19-3-1931 | R | Tewari, Shri Govind, M.A., Mathematics Department, Allahabad University, Allahabad. |
| 3-4-1933 | R | Thompson, (C. D.), M.A., Professor of Economics, Allahabad University. |
| 28-3-1931 | R | Toshniwal, (G.R.), M.Sc., Physics Department, Allahabad University, Allahabad. |
| 22-1 1934 | R | Vaugh, Mason, B.Sc., Agricultural Engineer, Allahabad Hindu University, Benares. |
| 17-4-1931 | R | Nehru, (S. S.), Institute, Naini, E.I.Ry. (Allahabad). |
| | | Vijayaraghavan, (T.), D.Phil., Reader, Mathematics Department, Dacca University, Ramna, Dacca. |
| 1-1-1930 | R* | Wali Muhammad, Ch., M.A., Ph.D., I.E.S, Professor of Physics, Lucknow University, Lucknow. |
| 15-9-1931 | R | Wall, (W. G. P.), M.Sc., I.E S., Associate I.E.E., M.R.S.T., Inspector of Schools, Allahabad Division, Allahabad |

*N.B.*—The Secretaries will be highly obliged if the members will kindly bring to their notice errors, if there be any, in their titles, degrees, and addresses.

# LIST OF MEMBERS OF THE PUBLICATION COMMITTEES
# 1933.

## Mathematics

1. Prof. A. C. Banerji, M.A., M.Sc., F.R.A.S., I.E.S., Professor of Mathematics, Allahabad University, Allahabad.

## Physics

2. Prof. M. N. Saha, D.Sc., F.R.S., Professor of Physics, Allahabad University, Allahabad.
3. Prof. Ch. Wali Mohammad, M.A., Ph.D., I.E.S., Professor of Physics, Lucknow University, Lucknow.

## Chemistry

4. Prof. N. R. Dhar, D.Sc., I.E.S., Professor of Chemistry, Allahabad University, Allahabad.
5. Prof. P. S. MacMahon, B.Sc., M.Sc., Professor of Chemistry, Lucknow University, Lucknow.

## Zoology

6. Prof. D. R. Bhattacharya, D.Sc., Ph.D., Professor of Zoology, Allahabad University, Allahabad.
7. Prof. K. N. Bahl, D.Phil., D.Sc., Professor of Zoology, Lucknow University, Lucknow.

## Botany

8. Prof. B. Sahni, D.Sc., Sc.D., F.L.S., F.A.S.B., Professor of Botany, Lucknow University, Lucknow.
9. Prof. K. C. Mehta, Ph.D., M.Sc., Professor of Botany, Agra College, Agra.

## Mining and Geology

10. Prof. K. K. Mathur, B.Sc., A.R.S.M., Professor of Geology, Benares Hindu University, Benares.

## Agriculture

11. Prof. C. Maya Das, M.A., B.Sc., I.A.S., Principal, Agricultural College, Cawnpore.
12. Dr. Sam Higginbottom, Principal, Agricultural Institute, Naini, E.I.R. (Allahabad).

# LIST OF EXCHANGE JOURNALS

| Journals | Publishers |
|---|---|
| 1. The Bell System Technical Journal ... | The American Telephone and Telegraph Coy., New York (U. S. A.) |
| 2. Proceedings of the Imperial Academy of Japan. | The Imperial Academy, Ueno Park, Tokyo. |
| 3. Journal of the Franklin Institute ... | The Franklin Institute of the State of Pennsylvania, Philadelphia, Penna, (U. S. A.) |
| 4. Bell Telephone System (Technical Publications). | The Bell Laboratories, New York. |
| 5. Collected Researches of the National Physical Laboratory. | The National Physical Laboratory, Teddington, Middlesex, England. |
| 6. Report of the National Physical Laboratory. | Ditto. |
| 7. The Electrician ... ... ... | The Electrician, Bouverie House, London. |
| 8. Proceedings of the Cambridge Philosophical Society. | The Philosophical Society, Cambridge. |
| 9. Proceedings of the Royal Society of Edinburgh. | The Royal Society of Edinburgh, Edinburgh, England. |
| 10. Journal and Proceedings of the Asiatic Society of Bengal. | The Asiatic Society of Bengal, Calcutta. |
| 11. Proceedings of the Indian Association for the Cultivation of Science. | The Indian Association for Cultivation of Science, Calcutta. |
| 12. Scientific Notes of the India Meteorological Department. | The Director-General of Observatories, Poona 5. |
| 13. Memoirs of the India Meteorological Department. | Ditto |
| 14. Bulletin of the Madras Government Museum, Natural History Section. | The Connemara Public Library, Egmore. |
| 15. Bulletin of the Patna Science College Philosophical Society. | The Patna Science College Philosophical Society, Patna. |
| 16. Journal of the Indian Institute of Science | The Indian Institute of Science, Bangalore. |
| 17. Transactions of the Bose Research Institute. | The Bose Research Institute, Calcutta. |
| 18. Current Science ... ... | The Indian Institute of Science, Bangalore. |
| 19. Transactions of the Royal Society of Canada. | The Royal Society of Canada, Ottawa. |
| 20. Fifty Years Retrospect, Anniversary Volume. | Ditto |
| 21. Journal of the Royal Astronomical Society of Canada. | The Royal Astronomical Society of Canada, Toronto, Canada. |

| Journals | Publishers |
|---|---|
| 22. Publications of the Dominion Astrophysical Observatory. | The Dominion Astrophysical Observatory, Victoria, Canada. |
| 23. Dominion of Canada Natural Research Council. | Ditto. |
| 24. Proceedings of the Royal Society of Victoria. | The Royal Society of Victoria, Melbourne, Australia. |
| 25. Journal and Proceedings of the Royal Society of New South Wales. | The Royal Society of New South Wales, Sydney, Australia. |
| 26. Transactions and Proceedings of the New Zealand Institute. | The New Zealand Institute, Wellington, New Zealand. |
| 27. Publications of the Alleghany Observatory. | The Alleghany Observatory of the University of Pittsburgh, Alleghany City (U.S.A.) |
| 28. Publications of the Observatory of the University of Michigan. | The Observatory Library, University of Michigan, Michigan (U. S. A.) |
| 29. Lick Observatory Bulletin ... ... | The Lick Observatory, University of California, Berkeley (U. S. A.) |
| 30. Proceedings of the American Academy of Arts and Sciences. | The American Academy of Arts and Sciences, Boston (U. S. A.) |
| 31. Memoirs of the American Academy of Arts and Sciences. | Ditto. |
| 32. Journal of Mathematics and Physics ... | The Massachusetts Institute of Technology, Cambridge, Mass. (U. S. A.) |
| 33. Proceedings of the National Academy of Sciences. | The National Academy of Sciences, Washington (U. S. A.) |
| 34. Proceedings of the Academy of Natural Sciences of Philadelphia. | The Academy of Natural Sciences, Philadelphia (U. S. A.) |
| 35. Year Book ... ... ... | Ditto. |
| 36. Astrophysical Journal ... ... | The Astrophysical Journal, University of Chicago, Chicago. Illinois (U. S. A.) |
| 37. Proceedings of the American Philosophical Society. | The American Philosophical Society, Philadelphia (U. S. A.) |
| 38. American Journal of Science ... | The American Journal of Science, New Haven (U. S. A.) |
| 39. Bureau of Standards, Journal of Research. | The Director, Deptt. of Commerce, Bureau of Standards, Washington (U. S. A.) |
| 40. Contributions from the Mount Wilson Observatory. | The Mount Wilson Observatory, Pasadena, California (U. S. A.) |
| 41. Communications (Solar Observatory) | Ditto. |
| 42. Annual Report of the Director of the Mount Wilson Observatory. | Ditto. |
| 43. Journal of Chemical Physics ... | The American Institute of Physics, New York, N. Y. |
| 44. Review of Scientific Instruments ... | Ditto. |

F. 3

| Journals | Publishers |
|---|---|
| 45. Transactions of the Astronomical Observatory of Yale University. | The Astronomical Observatory of Yale University, New Haven (U. S. A.) |
| 46. Publication in Zoology ... | ... The University Library, Exchange Deptt., Berkeley, California (U. S. A.) |
| 47. The Philippine Journal of Science | ... The Library, Bureau of Science, Manila P. I. (U. S. A.) |
| 48. Anzeiger (Mathematics and Science) | ... Akademie der Wissenschaften, Vienna, Austria. |
| 49. Almanack ... ... ... | Ditto. |
| 50. Anzeiger (Philosophy and History) ... | Ditto. |
| 51. Bulletin de La Classe Des Sciences | ... The Academie Royale de Belgique, Brüssels, Belgium. |
| 52. Annales De L'Institute Henri Poincare. | The Institut Henri Poincare, Paris (France). |
| 53. Mathematische Und Naturwissenschaftliche Berichte Ana Ungaru. | The Ungarische Akademie der Wissenschaft, Buda-Pest, Hungary. |
| 54. Sitzungsberichte Der Preussischen Akademie. | Preussischen Akademie der Wissenschaften, Berlin, Germany. |
| 55. Berichte Der Deutschen Chemischen Gesellschaft. | Deutsche Chemische Gesellschaft, Berlin, Germany. |
| 56. Nachrichten Von der Gesellschaft der Wissenschaften Zu Gottingen. Mathematisch-Physikalische Klasse. | Gesellschaft der Wissenschaften, Zu Göttingen, Germany. |
| 57. Geschaftliche Mitteilungen ... | Ditto. |
| 58. Mathematische Naturwissenschaftliche Klasse. | Bibliothekar, Heidelberger Akademie der Wissenschaften, Heidelberg, Germany. |
| 59. Berichte Der Mathematische Physischen Klasse. | Sachsische Akademie der Wissenschaften, Leipzig. C. I. |
| 60. Abhandlungen Der Mathematisch-Physischen Klasse. | Ditto. |
| 61. Sitzungsberichte der Mathematisch-Naturwissenschaftlichen. | Bayerische Akademie der Wissenschaften Zu Munchen, München, Germany. |
| 62. Communications from the Physical Laboratory, Leiden. | The Physical Laboratory, Leiden, Holland. |
| 63. Supplement, Communications from the Kamerlingh Onnes Laboratory. | Ditto. |
| 64. Rendiconti-Del Circolo Mathematico Di Palermo. | Palermo (Italy). |
| 65. National Research Council of Japan. ... | The National Research Council of Japan, Tokyo, Japan. |
| 66, Japanese Journal of Mathematics ... | Ditto. |
| 67, Japanese Journal of Botany ... | Ditto. |
| 68. Japanese Journal of Physics ... | Ditto. |
| 69. Science Report of the Tohoku Imperial University. | The Director of the Library, Imperial University of Tohoku, Sendai, Japan. |

| Journals | Publishers |
|---|---|
| 70. Proceedings of the Physico-Mathematical Society of Japan. | The Physico-Mathematical Society of Japan, Tokyo, Japan. |
| 71. Scientific Papers of the Institute of Physical and Chemical Research. | Komagome, Hongo, Tokyo. |
| 72. Journal of Science of the Hiroshima University (Zoology). | The Hiroshima University, Hiroshima, Japan. |
| 73. The Keijo Journal of Medicine    ... | The Medical Faculty, Keijo Imperial University, Chosen, Japan. |
| 74. Bulletin De L'Academie Des Sciences Mathematiques at Naturelles. | The Akademie der Wissenschaft, Leningrad, Soviet-Russia. |
| 75. Jouranl Du Cycle De Physique et De Chemie. | Academie des Sciences D'Ukraine, Kyiv, Ukraine. |
| 76. Journal Du Cycle Mathematique    ... | Ditto. |
| 77. Bulletin de La Classe des Sciences Physiques et Mathematiques. | Ditto. |
| 78. Memorias Do Instituto Oswaldo Cruz. | The Instituto Oswaldo Cruz, Brazil (U.S.A.) |
| 79. Physikalische Zeitschrift Der Sowjet-union. | Physical Journal of the Soviet Union, Kharkov, Chikovsakaya 16, Soviet-Russia. |
| 80. Geographical and Biological Studies of Anopheles Maculipennis in Sweden. | Kungliga Svenska Vetenskapsakademie, Stockholm, Sweden. |
| 81. Kungl. Fysiografiska Sällskapets Forhandlingar. | The Universitet, Lund, Sweden. |
| 82. Uppsala Universitets Arsskrift    ... | Universitet, Uppsala, Sweden. |
| 83. Compte Rendu Des Seances De La Societe De Physique et D'Histoire Naturelle. | Societe D'Histoire Naturelle et de Physique, Geneva, Switzerland. |
| 84. Comptes Rendus Mensuels Des Seances De La Classe De Medecine. | Academie Polonaise Des Sciences et Des Lettres, Cracovie. |
| 85. Comptes Rendus Mensuels Des Seances De La Classe Sciences Mathematiques et Naturelles. | Ditto. |
| 86. Bulletin International De L'Academie Polonaise Des Sciences et Des Lettres Classe Des Sciences Mathematiques et Naturelles. Serie A. | Imprimerie De L'Universite, Cracovie. |
| 87.    Ditto    Ditto    Serie B. 1. | Ditto. |
| 88.    Ditto    Ditto .    Serie B. 2. | Ditto. |
| 89. Bulletin International De L'Academie Polonaise Des Sciences et Des Lettres Classe De Medecine. | Ditto. |
| 90. Sprawozdania Z posiedzen Towarzystwa Naukowego Warszawskiego (History Literatury). | Societe des Sciences et des Lettres de Varsovie, Warsaw, Poland. |

| Journals | Publishers |
|---|---|
| 91. Sprawozdania Z posiedzen Towarzystwa Naukowego Warszawskiego (Phisiology). | Societe des Sciences et des Lettres de Varsovie, Warsaw, Poland. |
| 92.    Ditto    (Matematycznofizycznych) | Ditto. |
| 93.    Ditto    (Biologicznych)    ... | Ditto. |
| 94. Bureau of Fisheries (Document)   ... | The Commissioner of Fisheries, Washington (U.S.A.) |
| 95. Science Bulletin    ...    ... | University of Kansas, Lawrence, Kansas (U.S.A.) |
| 96. Mathematisk-Fysiske Meddelelser   ... | Kongelige Danske Videnskabernes Selskab, Copenhagen, Denmark. |
| 97. Biologiske Meddelelser.   ...    ... | Ditto. |
| 98. Transactions of the Royal Society of South Africa. | The Royal Society of South Africa, University of Cape-Town, Rondebosch, South Africa. |
| 99. Comptes-Rendus des Travaux Du Laboratoire Carlsberg. | The Carlsberg Laboratorium, Kobenhavn, Valby, Denmark. |

## JOURNAL SUBSCRIBED BY THE ACADEMY OF SCIENCES, U.P., DURING THE YEAR 1933.

### PHYSICS

1. Die Naturwissenschaften, 21 Jahrgang.    Hirschwaldsche Buchhandlung, Berlin, N.W.7.

# LIST OF PAPERS READ BEFORE THE ACADEMY OF SCIENCES, U. P., DURING THE PERIOD APRIL, 1933, TO MARCH, 1934.

1. "Colour and Chemical Constitution. Auxochromic Effect of Hydroxyl and Amino Groups on Phthalophenone Nucleus," by Narendranath Ghatak, M.Sc., Chemistry Deptt., Allahabad University, Allahabad.

2. "Chemical Examination of the Roots of *Thevetia Neriifolia* (Juss)," by Narendranath Ghatak, M.Sc., and G. P. Pendae, M.Sc., Chemistry Deptt., Allahabad University, Allahabad.

3. "On the Trematode Parasites of a Rangoon Siluroid Fish-Clarias Batrachus (Linnaeus 1785)," by R. C. Chatterjee, M.Sc., Helminthological Institute, University of Rangoon, Rangoon.

4. "On the Absorption Spectra of the Oxides of Zinc and Cadmium," by P. K. Sen Gupta, M.Sc., Physics Deptt., Allahabad University, Allahabad.

5. "The Absorption Spectra of the Vapours of the Lower Chlorides of Elements of the Fifth Group of Periodic Table," by Hrishikesha Trivedi, M.Sc., Physics Deptt., Allahabad University, Allahabad.

6. "A Note on the Vapour Pressure of Zinc Bromide," by M. S. Desai, M.Sc., Physics Deptt., Allahabad University, Allahabad.

7. "On the Absorption Spectra of Sulphides of Zinc and Mercury," by P. K. Sen Gupta, M.Sc., Physics Deptt., Allahabad University, Allahabad.

8. "On the Absorption Spectrum of Lead Monoxide and Lead Monosulphide," by R. S. Sharma, M.Sc., Physics Deptt., Allahabad University, Allahabad.

9. "On the Absorption Spectra of Hydrogen Peroxide," by R. S. Sharma, M.Sc., Physics Deptt., Allahabad University, Allahabad.

10. "On the Determination of the Values of $\gamma$ for Air Saturated with Water Vapour at Various Temperatures," by Haji Gulam Mohammad, M.Sc., Physics, Deptt., Allahabad University, Allahabad.

11 "A Contribution to the Morphology of *Digera Arrensis*," by S. P. Naithani, M.Sc., Botany Deptt., Allahabad University, Allahabad.

12. "On New Trematodes of Frogs and Fishes of the United Provinces, India."
    Part I. New Distomes of the Family Hemiuridae Luhe 1901 from North Indian Fishes and Frogs with a systemic discussion on the family Halipegidae Poche 1925 and the Genera Vitellotrema Guberlet 1928 and Genarchopsis Ozaki 1925," by Har Dayal Srivastava, M.Sc., Zoology Department, Allahabad University, Allahabad.

13. "On the Absorption Spectra of Some Higher Sulphides," by P. K. Sen-Gupta, M.Sc., Physics Deptt., Allahabad University, Allahabad.

14. "On the Absorption Spectra of Some Saturated Halides," by R. S. Sharma, M.Sc., Physics Deptt., Allahabad University, Allahabad.

15. "On New Trematodes of Frogs and Fishes of the United Provinces, India."
    Part II. On Three New Trematodes of the Sub-family Pleurogenetinae (family Lecithodendriidae) from Rana Cyanophlyctis of Oudh, by Har Dayal Srivastava, M.Sc., Zoology Deptt., Allahabad University, Allahabad.

16. "Effect of Direction of Speaking and of Pitch in the Assam Council Chamber," by B. C. Ghosh, Prof. of Physics, Vidyasagar College, Calcutta, and Satyendranath Ray, M.Sc., Lecturer, Physics Deptt., Lucknow University, Lucknow.

17. "On the Trematodes of Frogs and Fishes of the United Provinces, India."

> Part III. On a New Genus Mehraorchis and two New Species of Pleurogenes (Pleurogenetinæ) with a systematic discussion and revision of the family Lecithodendridæ, by Har Dayal Srivastava, M.Sc., Zoology Deptt., Allahabad University, Allahabad.

18. "On a New Trematode with Anus belonging to the Genus Opegaster Ozaki 1928, from an Indian Eel Anguilla Bengalensis," by K. R. Harshey, M.Sc , Zoology Deptt., Allahabad University, Allahabad.

19. "On the Synonymy of Caphalogonimus Magnus Sinha with Cephalogoniums Gangeticus Pande and the account of a New Species of the Genus," by B. P. Pande, M.Sc., Zoology Deptt., Allahabad University, Allahabad.

20. "Chemical Examination of the Seeds of *Abrus precatorius*, Linn."

> Part II. The colouring matter of the Seed-coat, by Narendranath Ghatak, M.Sc., Chemistry Deptt., Allahabad University, Allahabad.

21. "A Note on the Optical Activity of the Alkaloidal Salts of Violuric Acid," by Narendranath Ghatak, M.Sc., Chemistry Deptt., Allahabad University, Allahabad.

22. "On Synge's Paper", by S. Subramanian, Lecturer in Mathematics, Annamala University, Annamalainagar P. O., South India.

23. "Absorption Spectra of Coloured Organic Salts of Violantin and Alloxantin" by Kedar Nath Gaind and Sikhibhusan Dutt, Chemistry Deptt., Allahabad University, Allahabad.

24. "Chemical Examination of the Leaves of the *Nyctanthes Arborbristis* Linn," by Jagraj Behari Lal and Sikhibhusan Dutt, Chemistry Deptt., Allahabad University, Allahabad.

25. "The Problem of the Stellar Structure, Part I," by D. S. Kothari, Ph.D., Physics Deptt., Allahabad University, Allahabad.

26. "On the Absorption Spectra of the Halides of Elements of the Fifth Group," by Hrihsikesha Trivedi, M.Sc., Physics Deptt., Allahabad University, Allahabad.

27. "On|the Horizontal Comparison for the Location of Spectra of Heavy Elements," by S. C. Deb, M.Sc., Physics Deptt., Allahabad University, Allahabad.

28. "Cytoplasmic Inclusions in the Oogenisis of Passer Domesticus," by Murli Dhar Lal Srivastava, M.Sc., Zoology Deptt., Allahabad University, Allahabad.

29. "Chemical Examination of the Bark of *Nerium Odorum*," by G. P. Pendse, M.Sc., and Sikhibhusan Dutt, Chemistry Deptt., Allahabad University, Allahabad.

30. "On the Absolute Summability (A) of Fourier Series," by M. L. Misra, Mathematics Department, Agra College, Agra.

31. "On the β-ray Activity of Radioactive Bodies," by M. N. Saha, F.R.S., and D. S. Kothari, Ph.D., Physics Deptt., Allahabad University, Allahabad.

32. "Is the Neutron or the Proton the Fundamental Particle" ? by D. S. Kothari, Ph.D., Physics Deptt, Allahabad University, Allahabad.

33. "New Blood Flukes of the Family Spirorchisae Stunkard from Indian Fresh-Water Tortoises with Discussions on the Synonymy of Certain Genera and the Relationships of the Families of Blood-Flukes, Part II," by Dr. H. R. Mehra, Ph.D., Zoology Deptt., Allahabad University, Allahabad.

34. "Studies in the Viscosity Variations due to Chemical Reactions in Liquid Media," Part I, by Shridhar Sarvottam Joshi and Susarla Raju, Benares Hindu University, Benares.

35. "A Theorem Concerning the Zeros of the Laplace-Abel Integral," by Mr. S. P. Jain, M.Sc., Mathematics Deptt, Allahabad University, Allahabad.

36. "On the Absorption Spectrum of Nitrogen Monoxide in the Schumann Region," by Mr. P. K. Sen-Gupta, M.Sc., Physics Deptt, Allahabad University, Allahabad.

37. "On an Interpretation of Absorption Spectra of Molecules," by Mr. P. K. Sen-Gupta, M.Sc., Allahabad University, Physics Deptt., Allahabad.

38. "On Amphistome Parasites of Sheep and Goat from Allahabad," by Mr. K R. Harshey, M.Sc., Zoology Deptt., Allahabad University, Allahabad.

39. "On New Trematodes of Frogs and Fishes of the United Provinces, India."
     Part IV. Occurence and the Seasonal Incidence of Infection of Certain Trematodes in the Above Hosts, by Mr. Har Dayal Srivastava, M.Sc., Zoology Deptt., Allahabad University, Allahabad.

40. "Neutrons and Stellar Models," by Dr. D. S. Kothari, Ph.D., Physics Deptt., Allahabad University, Allahabad.

41. "On Experiments in Acoustic Correction of the U. P. Legislative Council Chamber, Lucknow," by Mr. Satyendra Ray, M.Sc., Physics Deptt., Lucknow University, Lucknow.

42. "On the Absorption Spectra of Some Simple Salts of the Transition Elements. Contribution to the Theory of the Co-ordinative Linkage $V^1$, by Messrs. R. Samuel and S. Mujtaba Karim, Physics Deptt., Muslim University, Aligarh.

43. "Chemical Examination of the Seeds of *Abrus Precatorious*, Linn."
     Part III. The Constitution of Abrine, by Mr. Narendranath Ghatak, M.Sc., Chemistry Deptt., Allahabad University, Allahabad.

44. "Synthesis of Substituted Cinchoninic Acids through the Knoevnagel Catalysts," by Mr. Madhusudanan Pandala, Chemistry Deptt., Andhra University, Waltair.

45. "The Application of Franck-Condon Principle to Continuous Absorption Spectra of Diatomic Molecules," by Mr. Hrishikesha Trivedi, M.Sc., Physics Deptt., Allahabad University, Allahabad.

46. "On a Formula for $\pi_v (X)$, by Mr. S. M. Shah, M.A., Mathematics Deptt, Muslim University, Aligarh.

47. "A New View about the Bacteriophage and the Filtrable Viruses," by Mr. Ramesh S. M. Prabhu, M.Sc., Chemistry Deptt., Benares Hindu University, Benares.

48. "The Effects of Different Fresh Fruit Juice Media on Certain Strains of Heminthosporium," by Mr. Pestonji R. Bhagwagar, M.Sc., Botany Deptt., Allahabad University, Allahabad.

49. "The Quantum Analogue of a Theorem of Poison in Classical Dynamics," by Dr. D. S. Kothari, Ph.D., Physics Deptt., Allahabad University, Allahabad.

50. "The Origin of Combined Nitrogen in the Atmosphere. The Analysis of Tropical Rain and its Importance in Agriculture," by Mr. Atma Ram, M.Sc., Chemistry Deptt., Allahabad University, Allahabad.

51. "Notes on Bessel Functions," by Dr. S. C. Mitra, Ph.D , Mathematics Department, Dacca University, Dacca.

52. "On the Absorption Spectra of the Oxides of the Alkaline Earth Metals," by Mr. P. K. Sen-Gupta, M.Sc., Physics Deptt., Allahabad University, Allahabad.

53. "Cytoplasmic Inclusions in the Oogenesis of Muska Domestica," by Mr. Murli Dhar Lal Srivastava, M.Sc., Zoology Deptt., Allahabad University, Allahabad.

54. "On the Summability of Fourier Series by Arithmetic Means," by Dr. B. N. Prasad, M.Sc., Ph.D., D.Sc., Mathematics Deptt, Allahabad University, Allahabad.

55. "Chemical Examination of the Seeds of *Plantago ovata* (Esabghol), by Messrs. G. P. Pendse and S. Dutt, Chemistry Deptt., Allahabad University, Allahabad.

56. "On a New Trematode from an Indian Fresh-water Fish," by Mr. B. P. Pande, M.Sc., Zoology Deptt., Allahabad University, Allahabad.

57. "Nuclear Structure, $\gamma$-Ray Fission, and Expanding Universe," by Prof. A. C. Banerji, I.E.S., M.A., M.Sc., Professor of Mathematics, Allahabad University, Allahabad.

58. "Chemical Examination of Punar-Nava or *Boerhaavia Diffusa*," by Messrs. Radha Raman and S. Dutt., Chemistry Deptt, Allahabad University, Allahabad.

59. "On Two New Trematodes of the Genus Opegaster Ozaki with a Systamatic Discussion on the Families Opecoelidae Ozaki 1925 and Coitocaecidae Ozaki 1928," by Mr. K. R. Harshey, M.Sc., Zoology Deptt., Allahabad University, Allahabad.

60. "On the Theory of the Absorption of Poly Atomic Molecules," by Mr. M. S. Desai, M.Sc., Physics Deptt., Allahabad University, Allahabad.

61. "On the Linkage of Certain Oxides," by Drs. H. Lessheim and R. Samuel, Physics Deptt., Muslim University, Aligarh.

62. "On Changes on the Circular Orbit of a Particle when Disturbed by Small Tangential and Normal Impulse," by Mr. Avadh Behari Lal, M.Sc., Ramjas College, Delhi.

63. "Effect of Temperature on Borax Solutions in the Presence of Polyhydric Substances and Organic Acids," by Mr. S. M. Mehta, Royal Institute of Science, Bombay.

64. On a New Distome Ascocotyle Intermidius from the Indian Fishing Eagle, with remarks on the Genera Ascocotyle looss 1899 and Phagicola Faust 1920, (Family– Heterophyidæ). by Mr. Har Dayal Srivastava, M.Sc., Zoology Deptt., Allahabad University, Allahabad.

65. "Fluorescent Radiation from $N_2O$," by Mr. P. K. Sen-Gupta, M.Sc., Physics Deptt., Allahabad University, Allahabad.

66. "The Electronic States of Tin monochloride molecule and its Electron quantum numbers," by Mr. Hrishikesha Trivedi, M.Sc., Physics Deptt., Allahabad University, Allahabad.

*Financial Statement—From 1st January, 1933, to 31st March, 1934*

| Receipts | Rs. | a. | p. |
|---|---|---|---|
| Opening balance on 1st January, 1933 | 8 | 12 | 3 |
| Bank balance on 1st January, 1933 | 2,425 | 0 | 6 |
| Government Grant (Non-recurring) | 2,000 | 0 | 0 |
| Allahabad University Grant for 1933-34 (Non-recurring) | 500 | 0 | 0 |
| *Membership Fee:—* | | | |
| Resident membership fee for 1931 | 60 | 0 | 0 |
| Resident membership fee for 1932 | 165 | 0 | 0 |
| Non-resident membership fee for 1932 | 10 | 0 | 0 |
| Resident membership fee for 1933 | 540 | 0 | 0 |
| Non-resident membership fee for 1933 | 180 | 0 | 0 |
| Resident membership fee for 1934 | 135 | 0 | 0 |
| Non-resident membership fee for 1934 | 50 | 0 | 0 |
| | 1,145 | 0 | 0 |
| Part payment of subscription for 1935 | 5 | 0 | 0 |
| Discount on outstation cheques of membership subscriptions | 1 | 0 | 0 |
| **Total Rs.** | 6,079 | 12 | 9 |

| Expenditure | Rs. | a. | p. |
|---|---|---|---|
| Establishment | 835 | 0 | 0 |
| Contingency (Including printing, postage stamps, and stationery, etc.) | 544 | 1 | 6 |
| Journals for 1933 and 1934 | 110 | 15 | 6 |
| Printing of Bulletin Vol. 2, Nos. 2, 3, and 4, 1932-33 | 1,402 | 9 | 6 |
| Printing of Bulletin Vol. 3, Nos. 1 and 2, 1933 | 705 | 3 | 6 |
| Binding of journals | 184 | 8 | 0 |
| Furniture | 42 | 0 | 0 |
| Bank Charges on outstation cheques | 5 | 12 | 0 |
| *Bank Balance :—* | | | |
| Building Fund 66 0 0 | | | |
| **Balance in hand   Rs. 2,183 10 9 | 2,249 | 10 | 9 |
| **Total Rs.** | 6,079 | 12 | 9 |

| *Details of Balance in hand   Rs. 2,183 10 9 | Rs. | as. | p. |
|---|---|---|---|
| Establishment | 5 | 0 | 0 |
| Contingency | 94 | 1 | 6 |
| Journals | 80 | 0 | 6 |
| Printing of Bulletin 1932-33 | 2,6 | 9 | 6 |
| Printing of Bulletin 1933-34 | 99 | 15 | 6 |
| Binding of journals | 12 | 0 | 0 |
| Furniture | 18 | 0 | 0 |
| Building Fund | 66 | 0 | 0 |
| | 2,183 | 10 | 9 |

D. R. BHATTACHARYA, D.Sc., PH. D., F.Z.S.,
*Hony. Treasurer,*
The Academy of Sciences of the United
Provinces of Agra and Oudh.

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### Message from His Excellency Sir W. Malcolm Hailey, The Patron of the Academy

*This meeting of the Academy of Sciences receives additional importance from the proposal for an all-India Academy which was mooted at the recent Science Congress held at Bombay. The share taken by some of the members of the U. P. Academy of Sciences in that Congress shows the importance which the Academy has attained in the scientific world of India; every one will, I am sure, hope that it will receive increasing support and achieve continued success.*

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*(Sd.) W. M. Hailey,*
*Governor,*
*United Provinces.*

</div>

*January 5, 1934.*

### Message from The Hon'ble Mr. J. P. Srivastava, The Minister of Education, U. P.

*Thank you so much for your letter of the 3rd. I am so sorry it will not be possible for me to be present at the third annual meeting of the Academy of Sciences which will be held at Allahabad on Saturday, January 20, 1934, as I have another engagement for that day. I am, however, watching the progress of your Academy with great satisfaction. I am sure it will in time become the premier academy of its kind in India. From all accounts the Science Congress at Bombay has been a great success and I am proud of the part which the U. P. scientists played in it.*
*With kind regards,*

<div align="right">

*Yours sincerely,*
*(Sd.) J. P. Srivastava,*
*Minister of Education,*
*United Provinces.*

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*January 8, 1934.*

# PRESIDENT'S ADDRESS

## ADDRESS OF THE PRESIDENT, PROFESSOR K. N. BAHL, AT THE ANNIVERSARY MEETING HELD ON JANUARY 20, 1934.

THE HON'BLE THE CHIEF JUSTICE, FELLOWS AND MEMBERS OF THE ACADEMY, LADIES AND GENTLEMEN,—My very first duty as President of the Academy is to accord on its behalf a hearty welcome to the Hon'ble Sir Shah Mohammad Sulaiman, Kt., M.A., LL D., the Chief Justice of the Allahabad High Court, who has kindly come over to preside at our anniversary meeting this afternoon. Although his main work lies in the administration of Law and Justice, he is known to take a keen interest in science. He has been a member of our Academy since its inception and I understand that he employs his spare time these days in the study of higher physics and in researches on theory of the universe, a subject on which he has promised to give us his own views this afternoon. We all hope that his association with us will help us in furthering the cause of scientific research in these provinces.

We are assembled to-day to celebrate so to speak, the third birthday of our Academy, which now enters the fourth year of its existence. In this country, almost notorious for its heavy infant-mortality, it is a matter for congratulation that the Academy, under the fostering care of Dr. M. N. Saha, its founder and first President and Professors Banerji and MacMahon, its energetic and painstaking secretaries, has not only survived its period of infancy but is showing signs of developing into a healthy and promising child.

The honorary secretaries have placed before you an account of the progress made by the Academy during the year and I am sure, you will all agree, that with our limited resources, we have achieved a great measure of success. We wish to expand our activities in several directions but we lack the means for such expansion. And I have no doubt that as our work receives the appreciation it deserves, the Government and public at large will give us the financial support that we need.

I have selected "The Present Position of Darwinism" as the subject of my address, as the doctrine of Evolution forms one of the two most important generalizations of Biology and is also of application in other branches of human knowledge.

## Present Position of Darwinism

The year 1858 forms a landmark in the history of scientific progress, nay even that of human thought, since it was in that year that Darwin and Wallace

formulated the great principle that Organic Evolution had occurred chiefly as a result of the action of *Natural Selection.* That evolution had taken place was known long before; Darwin even Darwin's grandfather Erasmus Darwin believed in the fact of evolution—in fact, some people have even traced the idea of evolution in the writings of ancient Greeks like Lucretius and Empedocles, but the great achievement of Charles Darwin was to give a satisfactory explanation, supported by copious evidence, of the *factors* which had brought about evolution. We must, therefore, at the very outset distinguish between the *fact* of evolution and the *theories* of evolution, for we must remember that " Darwin did not discover Evolution, as many people suppose, but he gave an account of the operating causes for the process of evolution."[1] That evolution has taken place is a fact supported by incontrovertible evidence and forms not only the accepted creed of all scientific men but has even permeated the thought and vocabulary of historians and political philosophers and even of theologians. But *how* evolution has taken place is the crucial question and Charles Darwin's great contribution was the answer to this question. Seventy-five years have elapsed since the publication of Darwin's classic, the " Origin of Species" and I shall attempt during the short time at my disposal to discuss how far the Darwinian hypothesis of Natural Selection has stood the test of critical biological thought.

Professor Huxley, who was a most ardent champion of Darwin's theory and called himself " Darwin's bull-dog," summarises the Darwinian hypothesis in these words :—

" All *species* have been produced by the development of varieties from common stocks : by the conversion of these, first into *permanent races* and then into *new species,* by the process of *natural selection,* which process is essentially identical with that of artificial selection by which man has originated the races of domestic animals—the *struggle for existence* taking the place of man and exerting, in the rase of natural selection, that selective action which he performs in artificial selection."[2]

Darwin observed that variations occurred in nature; he postulated that these would be inherited from generation to generation and that in the multitude of individuals produced by every living species, all competing against each other for food and a place under the sun there will be a *struggle for existence* and consequently the *survival of the fittest.* The chief factors contributing to the process of evolution, according to Darwin, were variation, heredity and the struggle for existence leading to Natural Selection.

Let us begin our discussion by considering the nature, origin and inheritance of variations. Unfortunately our knowledge of this part of the

[1] Wells, Huxley and Wells—*The Science of Life*, 1931.
[2] Huxley's Collected Essays—Vol. II, p. 71.

subject was extremely limited in Darwin's time but the great impetus given by the Darwinian theory has resulted in a rich harvest of observed facts and experimental deductions, which have led to a correction and re-statement of this part of Darwin's theory. We are all familiar with the fact that parents and offspring, brothers and sisters are never quite alike; they always differ from each other and we call these differences *variations*. This variability occurs in every kind of character, shape, size and colour in simple cases of plants and animals, while in man "the most complex capacities, such as fertility, the power of resistance to disease, and intellectual ability are notoriously variable." [1] We can think of the enormous possibilities of variation, if we bear in mind the fact that variation may occur at any or all stages of life in the egg, the embryo, the young or the adult of an animal and of a plant.

But in spite of these variations, which are sometimes very striking, we have the great principle of heredity working all the time and it is this great conserving force that accounts for the countless resemblances in the whole organisation of one generation and the next. When the characters of a parent re-appear in the offspring, in popular language we say that the characters are inherited. In sexual reproduction, the male contributes the sperm and the female the egg and these two together go to make up the offspring. The offspring is, therefore, really a growth of the detached bits of its parents; [1] "it is a chip of the old block", in fact of two blocks since there are two parents. The great German zoologist Weismann put forward the idea that as it is part of a man and a woman which grows into their children—it is really their own living substance which is handed on from generation to generation and he used the term *germ-plasm* for this immortal bit of the organism to distinguish it from the *soma* or the remainder of the body which is mortal. The *soma* lives and dies but the germ-plasm goes on indefinitely. If life had a single origin, all the living organisms would be traced to one stock—they would all be the twigs of the original tree or trunk of the germ-plasm. This conception of Weismann is called the theory of the *continuity of germ-plasm*. We can thus think of an actual material continuity between our own germ-plasm and that of the original living organism that first appeared on the surface of this earth.

The question naturally arises as to how it is that with this continuity of germ-plasm, we have the wonderful variety and diversity of form that we find amongst organisms. We must have variation in the germ-plasm in order to have any variation amongst organisms at all. The older naturalists assumed that the use and disuse of organs and the external environment generally induced changes in the organisms and that these changes were

[1] Goodrich—*Living Organisms*, 1924.

transmitted and reappeared in the progeny. This point of view was specifically put forward long before Darwin by the French naturalist Lamarck who gave as example the case of the long neck of the giraffe; according to him the ancestral giraffe stretched its neck to reach the leaves of the higher branches of trees, the offspring kept up this useful habit which was inherited, so that by generations of continuous stretching of the neck, the species has acquired this permanent character of a long neck. Lamarck would seem to say, "Master what you can of Mathematics and your child will calculate with greater ease. "[1] Darwin himself was hard put to explain the origin of variations and for want of an adequate explanation, he accepted that variations were the effects of differences in environment but he was not quite comfortable about the matter since he wrote to Huxley, "If, as I must think, external conditions produce little effect, what the devil determines each particular variation."[2] Unfortunately Lamarck's theory of the inheritance of acquired characters has not been able to stand the test of critical examination and has been largely overthrown. Weismann tested it experimentally by cutting off the tails of mice, generation after generation, but the young mice continued to grow tails. Similarly the effects of use and disuse, *e.g.*, the enlargement of muscles in the arm of a blacksmith or even the results of education have not been proved to be inherited as such from one generation to the next. The fact is, as Weismann postulated, that the change induced in the *soma* or body cannot be transmitted to the offspring; for any hereditary change, the *germ-plasm* must be modified. These conclusions of Weismann form a most important contribution to the science of evolution since the time of Darwin.

Another valuable point of view first advocated by Professor Sedgwick and developed later by Sir Archdall Reid and other is that each character of an organism is the product both of factors of inheritance in the germ-plasm and of environment and can only be reproduced when both are present. Not only every part of an organism but all its habits and activities are the results of the combined action of factors of inheritance and environment. We can distinguish between the effect of a factor of germ-plasm and that of the environment by a simple example. There is no more fundamental character of a green plant than its greenness. Yet if we grow the seed of the greenest plant in a dark chamber, the plant will not be green. The environmental stimulus of light is absent. We may say that "the green character is not transmitted, it is not inherited." [3] But what is really inherited is the capacity to become green and this capacity is present in the factors of the

[1] Wells, Huxley and Wells—*The Science of Life*, 1931.
[2] Haldane—*The Causes of Evolution*.
[3] Goodrich—*Living Organisms*, 1924.

germ-plasm, as can be seen at once by bringing the pale seedling into light, when it will turn green in a day or two. The presence of iron in the soil is another necessary condition for the development of green colour. The plant may have the necessary capacity and the brightest of sun-light, but lack of iron will not give the green colour. Similarly, the common belief that tuberculosis is transmitted from parent to offspring is fallacious. Tubercle bacilli are present almost everywhere in crowded streets and dirty surroundings but if your constitution is strong and your lungs healthy, you will not develop tuberculosis. What the offspring of a tuberculous patient will inherit will be a weak constitution and lungs susceptible to disease and if by adequate nourishment and other means, the constitution is made strong and the children are kept in clean and healthy surroundings, they need have no fear of getting tuberculosis at all. An organism, therefore, is the result of the interplay of the factors of inheritance and the conditions of the environment. In order to have a healthy plant, you need not only good seed but also a good well-manured soil.

From the point of view of variations, therefore, we must distinguish between variations produced by a germinal change in a constant environment and variations which are induced by a change in environment only while the germinal constitution continues the same. The former are called *mutations* and the latter *modifications*. These variations cannot be distinguished by a mere inspection but only by systematic observation and experiment. The analysis of variations by these means has been carried out only during the last 30 years and has yielded very interesting and useful results which constitute another notable advance in our knowledge of the process of evolution.

The impetus for this analysis of variations was provided by the re-discovery of Mendel's monumentel work in 1900. Working in the seclusion of the cloister garden at Brunn, this Austrian monk carried out experiments for eight years on the common pea plant and published his work in 1865, only six years after the publication of Darwin's " Origin of Species." For 35 years, his work was neglected but since 1900 it has become very famous. In simple terms, Mendelism postulates that it is the gametes, the egg and the sperm in the case of animals and the polien-grain and the ovule in the case of plants that carry the factors which are capable of giving rise to the characters of animal and plants. These factors are now called *genes*. Further, a given gamete can carry one and only one of any alternative pair of characters. In the pea plant, for example, it can carry either tallness or dwarfness but not both. In biological language, we describe this as Mendel's law of the *purity of the gametes*. If a tall pea plant has been crossed with a dwarf and the hybrids grow and flower, there will be a segregation of the characters tallness and dwarfness at the time of the formation of the gametes. With this simple principle added

to the law of dominance as a guide, biologists have built up a whole science of Heredity or Genetics and have succeeded wonderfully in extending the scope of Mendel's work and its applications. Through a knowledge of Mendel's law, biologists have been able to raise the desired breeds of animals and plants; they have been able to explain the mechanism of the determination of sex and the transmission of several diseases in man; in fact, Mendelism has provided the key to the working mechanism of heredity. We in India owe a deep debt of gratitude to Mendel whose discovery led Sir Rowland Biffen to raise a rust-proof variety of wheat at Cambridge and this in turn led the Howards at Pusa to raise the famous Pusa varieties of wheat which are gradually replacing the old indigenous varieties and which account for the increasing prosperity of the wheat-growing areas in the United Provinces and the Punjab. Similarly breeds of cow with a high rate of milk-yield have been raised and also breeds of poultry with a high rate of egg-production.

The thrilling problem of the determination of sex attracted a number of distinguished workers who have succeeded in elucidating the mechanism of sex-heredity. Doncaster and Raynor in England were the first to discover the phenomenon of sex-linked inheritance; Goldschmidt in Germany has worked out the mechanism of the so-called "intersexes," but the most outstanding contribution has been made by Morgan and his colleagues in America, who have carried the analysis a stage further by correlating sex-heredity with the differences in the chromosome constitution of the cells of the two sexes. In recognition of this work of his school, Thomas Hunt Morgan has only recently been awarded the Nobel Prize. A start was made by proving that sex is a definite, heritable character, exactly comparable to the tallness and dwarfness of the pea-plant or the black and blue colour of the eye in man. Cases of sex-linked inheritance were next worked out in moths and poultry, and finally in the fruit-fly *Drosophila*, the determination of sex was definitely proved to belong to one particular chromosome, the sex-chromosome. In man, two kinds of sperms—male-determining and female-determining—have been demonstrated, so that we now know exactly *how* sex is actually determined. Unfortunately we cannot yet *control* sex, although vigorous attempts are being made to discover a means of separating the male-producing from the female-producing sperms in order to paralyse one set or the other as desired. These attempts have not been successful thus far, but it may be not long before some one solves the problem and we may then have the means ready to decide the sex of our children and satisfy many people who are desperately anxious to have a child of a certain sex.

Several human defects and diseases have been shown to follow the line of simple Mendelian inheritance. Presenile cataract of the eye, night-blindness and colour blindness have been proved to follow Mendelin inheritance;

so does *haemophilia*, a disease which afflicted the late Tsar's ill-fated son and which brought the Tsarina, as the story goes, under the influence of Rasputin. Specially poignant to the Tsarina must have been the knowledge that this disease is transmitted by the mother herself to her sons alone. As our knowledge of heredity has increased, we have discovered out that certain diseases cannot be rooted out; they inevitably pass on from one generation to the next. Inherited feeble mindedness is one such disease and one can understand why Germany has made a law for compulsory sterilisation of the feeble minded and why there is a movement in England as well for a similar law although on a voluntary basis.

From the point of view of Darwinian Evolution, however, the chief contribution of Mendelism is to establish that heritable variation has a definite basis in the gamete and that it arises by a sudden step it is discontinuous, because it is based upon the presence or absence of some definite factor or factors in the gametes from which it sprang. Darwin's view was that a character was developed by the gradual accumulation of minute variations occurring at random and he emphasised this point by using a Latin phrase "*Natura nihil facit per saltum*" *i.e.*, Nature does not work by jumps. Bateson in 1895 pointed out that species do not pass gradually from one to the other but the differences between them are sharp and definite "Why don't we get intermediates of all sorts more frequently in nature?" he asked, "if specific differences arise by an accumulation of minute and almost imperceptible differences." De Vries, on a prolonged study of the evening primrose *Oenothera* concluded that new varieties arose from older ones by sudden sharp steps or "mutations." Finally all the work on Mendelian lines has convinced biologists that Darwin's idea of the summation or accumulation of minute random variations must be abandoned and that we must regard variations appearing as "sports" or mutations and their origin as due to the addition or subtraction of factors in the gametes. Once formed, natural selection decides whether these new characters will persist or not. It is these mutations, therefore, that furnish the raw materials of evolution. But the explanation is still incomplete. We have localised problem but have not succeeded in solving it yet. The origin of the new mutations has yet to be explained satisfactorily. Some biologists believe that in the course of the maturation of the germ-cells, which is a very important phase in their development, there is a re-shuffling of the cards in the pack of factors of hereditary characters; others attach great importance to fertilization or crossing and this is not surprising when we remember that two very complex systems, usually of diverse origin, become in the act of fertilization a unity that develops in most cases into a harmonious life. In fact, there is ample experimental evidence to show that novelties are induced by crossing but unfortunately

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this factor alone does not seem sufficient to account for the origin of all new specific variations.

I now pass on to the essential part of the Darwinian hypothesis, *i.e.*, the action of *natural selection*, in respect of which Darwinism has emerged unscathed even from a most exacting scrutiny. In his "Origin of Species," Darwin emphasised in the first place the fact that living organisms multiply in geometrical progression and thus constantly tend to press upon their means of subsistence, this idea being probably due to Malthus. We know from observation that the daily life of animals and even of man is primarily a hunt for food; in fact, according to a French writer, life can be summed up in the conjugation of the verb "to eat"—its pleasant active voice (except for the dyspeptic) and its awful correlative, the passive[1]. In general, the total population of any region of the earth is a direct reflection of the balance between "I eat, you eat, he eats, etc." and the passive—"I am eaten, you are eaten and he is eaten, etc."[1]. Darwin took the example of the elephant as the slowest breeder amongst animals and estimated that if all the progeny of a single pair survived, in 500 years we shall have 15 million elephants. Yet the average number remains more or less steady, which means that only two young ones of a pair survive the rest die out. In this process it is the better equipped that survive and the worse-equipped die. The struggle for existence acts like a sieve; it selects those that possess advantageous variations and eliminates the useless and the undesirable.

That natural selection is at work all the time has now been proved experimentally, although such experimental evidence was lacking in Darwin's time. In 1904, di Cesnola tied up 20 green and 45 brown specimens of *Mantis* in green grass and found that after 19 days, 35 browns had been eaten by birds but none of the greens. Similarly when he tied brown and green *Mantises* on brown grass, the greens were all eaten while all the browns remained alive.[2] Here was natural selection at work through the agency of birds. Recently in 1920, Harrison has brought forward evidence to show natural selection at work among the moths of the species *Oporabia autumnata* in a mixed wood of pine and birch in Yorkshire, and several other workers have adduced similar evidence.

I shall not take your time in enlarging any further on this—the most important aspect of Darwinism, nor shall I deal, as I would very much like to, if I had the time with "isolation" as a maker of species, nor with the interesting question of Orthogenesis or straight-line evolution.

To sum up, we must conceive of a living organism as a complex of a large number of characters subject to mutations in succeeding generations.

[1] Dakin—*Introduction to Biology*.
[2] Haldance—*Causes of Evolution*.

These mutations are called forth by a change in the germ-plasm and are inherited. "But since many differences of an advantageous or disadvantageous sort exist and are inherited, the struggle for existence or natural selection acts on a species like a filter or a sieve. It selects types of success and failure, sets a premium on advantageous variations and continually removes a large majority of the disadvantageous ones, so that the average of the species moves in. the advantageous direction." [1] Darwinism thus stands vindicated to-day; it has emerged almost unchanged after a most critical examination extending over three quarters of a century and serves to account for the process of Evolution with a cogency and a completeness unequalled by any other explanation.

[1] Wells, Huxley and Wells—*The Science of Life*, 1931.

## ADDRESS BY THE HON'BLE SIR SHAH MOHAMMAD SULAIMAN, Kt., M.A., LL.D., CHIEF JUSTICE, HIGH COURT, ALLAHABAD.

LADIES AND GENTLEMEN,

It is a great honour for me to preside at this assembly of learned scientists and I certainly feel that it is rather audacious on my part to attempt to discuss before you any scientific subject, in which I have not the time to specialise. But I can feel no hesitation in referring to the remarkable progress which the Academy of Sciences has made during the short period that it has been in existence.

As Prof. Banerji, the Hony. General Secretary, has shown in his Report for the last year, the number of members on the roll of the Academy has been steadily increasing. If this progress is maintained, as it is sure to be, the Academy will be a fully representative body of scientists engaged in scientific study or teaching work or in research.

The Bulletin issued by the Academy has contained valuable papers of a high order on various scientific subjects, which have been very much appreciated. The authors of the articles deserve to be congratulated on the valuable contributions made to the advancement of scientific knowledge. That the value of the Bulletin is fully recognised abroad is amply evidenced by the fact that it is already receiving in exchange about one hundred scientific Journals from almost all parts of the world. The Bulletin in this way is playing an important part and helping to build up a library of up-to-date scientific literature.

The success achieved so far has been due mainly to the inspiration and encouragement received from His Excellency Sir Malcolm Hailey, the Patron of the Academy, as well as to the enthusiasm and devotion of its Presidents, Secretaries and other office-bearers, who are sincerely endeavouring to raise it to the status of an All-India Academy of Sciences.

The branches of Science have now become so numerous and the accumulation of knowledge in each branch so vast, that even a whole-time scientist can never hope to master them. Much less can an amature like myself feel competent enough to deal with the engrossing problems of all the branches of the Science. I confess, I know very little about Biology. All of us have some perfunctory knowledge about evolution, but few of us know the details of thrilling problems like the determination of sex. But we are all indebted to Prof. Bahl for his very lucid and clear exposition of Darwinism. For the teeming millions who know nothing about birth control, it is certainly a happy news to be told that offsprings of tuberculous patients do not inherit the

disease. Physics is the only subject of which I have managed to keep up some knowledge in a very limited way. I have, therefore, to confine my address to one aspect of Modern Physics, which of all others is the most mysterious and an apparently unintelligible phenomenon. The present conception of light as the origin of all the modern troubles has led to the propounding of most amazing theories and apparently contradictory assumptions. The answers offered for some of the perplexing questions concerning the nature of light are designed to take us deep into the realm of unreality, where we not only lose all mental picture of it, but it becomes so illusory as to be entirely beyond our comprehension. Eminent scientists have to admit that the present theories have landed us in a *cul de sac* and there seems to be no way out of it without retracing our steps.

I have ventured to prepare my written address in the hope that a destructive criticism from an outside source, based upon a collection of the existing anomalies and contradictions, and if I may be permitted to say so, even absurdities in the modern ideas, may not only expose the utter inadequacy of the present day accepted views, but may perhaps pave the way for a new constructive theory, that will get over the existing difficulties.

As copies of my printed address are available to you all, I am relieved of the necessity of reading the whole of it. I shall accordingly content myself with reading only portions of it here and there.

## THE ADDRESS

It is a great privilege to me to be invited to preside at this session of the Academy of Sciences. I have accepted the honour with considerable diffidence, because it is somewhat presumptuous on the part of any outsider to intrude upon the consecrated precincts of Science and be bold enough to make a critical survey of the development of any of its branches. One, who is absorbed in other engrossing pre-occupations and can hardly spare time for a devoted pursuit of scientific knowledge, much less its experimental side, would naturally hesitate to attempt to examine the very foundations upon which some of the modern conceptions of the structure of the Universe are based. But liberty of thought is not the sole monopoly of great scholars and eminent scientists only, and the portals of even a sacred cloister have, on occasions, been allowed to be invaded by an outside observer. I may, therefore, be excused for a somewhat similar encroachment.

In spite of the vast accumulations of the store of scientific literature, it must be admitted that human knowledge is still very much in its infancy. Our abysmal ignorance is at once revealed when we endeavour even to comprehend the vastness of the Nature around us. When we try to appreciate that the Sun, whose size is more than one million three hundred thousand times that of the Earth we inhabit, might well have existed for the last eight

million million years, that the Earth itself must have existed for the last two thousand million years and may yet last for a much longer period, that life on this Earth might well have existed for three hundred million years, while man could have hardly lived on it for more than three hundred thousand years, it becomes apparent that the period of a few thousand years during which the stock of human knowledge has been growing is but a negligible infinitesimal fraction of time, a mere drop in the fathomless ocean.

The great Sun is only a tiny speck in the vast Universe. Light travelling at the stupendous rate of 186,000 miles per second takes about eight minutes to come to the Earth from the Sun. But the light from even the nearest Stars takes not seconds, minutes, hours, days and months, but four years and a quarter, or more, to reach the Earth. There are some four hundred thousand million Stars, including our Sun, which form one Galactic system, bounded by the Milky Way, across which light at that terrific speed would take two hundred and twenty thousand years to travel from one end to the other. Outside this huge Galactic system there are still more distant nebulæ, some two millions of which are now visible in the great 100-inch telescope at Mt. Wilson. The most distant of these nebulæ revealed at present are so far away that light at the rate of one hundred and eighty six thousand miles per second would take one hundred and forty million years to come to the Earth. What further depths of space would be revealed if a 200-inch telescope now in contemplation is constructed! But even this will admit only about a million times as much light as an unaided eye. And it is at present beyond our comprehension what still bigger Supergalaxies and still greater Metagalaxies would not be revealed, when astronomical instruments improve further, and in what inconceivably gigantic dimensions Universes surrounding Universes would not be disclosed. In face of these staggering figures, the utter insignificance of Man's place in this vast Universe can be readily realised. This Outer World represents but one side of the range of human vision.

On the other side, we have the minutest particles constituting worlds within worlds. Matter has been found to consist of molecules of a hundred-millionth inch in diameter, so minute that a pint of water would contain twenty million, million, million, million molecules, the weight of each being of the dimension a million million million millionth fraction of an ounce. Each such molecule consists of two or more atoms. Some two hundred and fifty varieties of atoms (including isotopes) of smaller sizes have been discovered, which account for ninety different elements. In its turn, every atom consists of electrons and a nucleus. An electron has a radius of 5 million millionth part of a centimeter. It revolves round its nucleus several thousand million million times every second. The nucleus, though in fact much heavier, is so condensed that it is even smaller in size than an electron. But all these are heavier bodies as compared to light particles, if they at all exist.

To imagine the speed at which these may be vibrating it may be mentioned that an electron vibrates at the rate of 124 million million million complete oscillations per second. Protons constituting the nuclii may be vibrating at even a greater speed of 229 thousand million million million oscillations per second. As Science is making tremendous strides, it is impossible to hazard even a guess what further inner-most depths of the Inner World will not be disclosed very soon.

Standing somewhere perhaps mid-way between the Unknowns on the two sides, Man's power of observation is strictly limited between apparently very narrow limits. As scientific knowledge progresses, these limits will no doubt be extended further and further on both sides, and yet our knowledge will ever remain very meagre and scanty. We can only have mere glimpses of the vast expanse of Nature, and our theories are but conjectures and speculations as to the ultimate Reality. Yet in spite of all our hopeless imperfections, advance is being made rapidly in increasing geometrical progression. The last decade has brought about a tremendous revolution in scientific thought. The conception of the Universe as a great machine working in an ordered way has completely collapsed. Nature is now regarded as being capricious and arbitrary, and her processes as sudden jumps, and uncertain jerks, without following any methodical Law of Causation. The Law of Causation has been dethroned from the honourable position which it had previously occupied, and its prominent place has been taken by a new Law of Indeterminacy which inexorably lays down not only a subjective, but even an objective Uncertainty. Everything in the Universe is now believed to be comprised of mere imaginary waves of Probability and Chance, so that nothing substantial, tangible or real exists in it.

I propose to scrutinise the very basis upon which Modern Science has built this huge, but imaginary structure, by considering first the successive steps which have driven us into such a desperate and helpless position. The principal origin of the trouble lies in the conception of light, to which alone I shall confine myself. I may be permitted to begin with a historical background, showing how and why various theories have had to be abandoned, giving place to present day conceptions. As this assembly of learned men and women consist of Physicists as well as non-Physicists, I fear I cannot make myself intelligible, without a somewhat detailed survey.

It is not too much to presume that when the human mind became sufficiently developed, one of the very first wonders which would have struck it must have been the mystery of vision. Eyesight is our dearest possession. Half of the happiness of life would be gone if we lost our vision, and missed all the glories and beauties that surround us. Our very comprehension of the magnificent design of the Great Maker would be lamentably incomplete if we had no means of observing the multifarious manifestations of Nature. One

can imagine the ancient philosophers asking themselves some such questions as these : How are bodies visible though they are at a distance ? How do we see things, which we cannot touch ? How are various objects perceptible at all ? How is there a connection between the eye which sees and the object seen ? But no serious endeavour was made to answer them for ages.

The ancient thinkers believed in a multiplicity of divinities, and felt no difficulty in attributing every observed phenomenon to a direct intervention of the gods. There was a Sun god who was responsible for sending out all the light and heat from the Sun to the Earth, and there was a god of fire who gave us fire from which heat and light were produced on the Earth itself. Another god caused lightning and thunder. The ancient philosophers did not feel themselves called upon to investigate the origin of heat or light. They took it for granted that such phenomena were mere creations of divine beings. It is therefore not surprising that the great minds of the early Assyrian, Egyptian and Aryan philosophers were not concerned with the mysterious phenomenon of vision, for in it they hardly saw any mystery at all. The early Persians or Iranians in the same way regarded fire as a divine manifestation. When Zoroastrians worshipped the sacred fire, their learned men could not be expected to pry into the genesis of what to them was nothing short of a symbolical embodiment of the divine being. One can safely presume that up to the time of the religious leader Zoroaster زردهشت (1000 B. C ) there was no occasion to bestow any serious thought on the physical problem of light

So far as available historical records show the credit of making the first attempt to tackle this question must go to the early Greek philosophers In spite of their beliefs in super-human agencies they endeavoured to evolve some intelligible theories to explain the mystery of vision. The name of the great philosopher Pythagoras فيثا غورس (572-497 B. C ) stands out in eminence for being the first to put forward a rational hypothesis. In his conception of the Universe as consisting of spheres moving in perfect harmony round the earth as centre, producing beautiful tones of music, he regarded all objects as an integral part of the harmonious whole. He conceived that light consisted of small particles that were thrown out from the object seen and entered the eye and this caused vision. According to him the particles were continually projected into the pupil of the eye, and thereby enabled men to see things. He was undoubtedly the first propounder of what later on came to be described as the Corpuscular Theory of Light.

Some 100 years after, the great Italian philosopher Empedocles انبيذ قليس (444 B C.), who belonged to the Pythagorean school, conceived the world as consisting of four fundamental elements, earth, water, air and fire عناصر اربعه. He rightly regarded all luminous bodies as the seat of fire ; but his conception of light was that vision was effected by something emitting from the eye itself which after meeting something else emanating from the object excited the

sense of sight. This curious view could not be completely exploded till the advent of photography in recent times which dispensed with the eye for the purposes of vision. About the same time Philolus نللارس (430 B. C.) considered that all the heavenly bodies revolved about a "central fire" which, however, was not visible to the inhabitants of earth, as the earth's face was always turned away from it. All the same it was the source of all heat. Anaxagoras الكـا غورس (450 B. C.) reverted to the Pythagorean idea and regarded the Sun as a hot stone, from which light was emitted and believed that the moon shone by reflected light.

Another century later, Plato فلاطون (350 B. C.) the famous disciple of Socrates سـقراط (470-399 B. C.), but greater than his master, founded a new school of philosophy. Quite in keeping with his natural religious tendencies, his philosophic mind combined the Zoroastrean conception of the divine element in fire, the Pythagorean idea of emission from objects, the Empedoclian assumption of emission from the eye, and added something of his own. His idea of vision was that it was caused by three distinct elements (1) divine fire emerging from the eye (2) light of the Sun following on an object and (3) emanations from the object seen. A visual stream of divine fire or rays emitted by the eye united with the light of the sun, and together combined with the emanation from the object, and in that way completed the act of vision.

His greatest disciple Aristotle ارسطا طاليس (340 B. C.) for the first time put forward an entirely original hypothesis that light is not at all a material emission from a source, nor any emanation from the eye, but is a mere property of or due to an action of the medium between the eye and the object. This was without doubt the first known origin of the modern Wave Theory of light.

The notion of Euclid اقليدس (340 B. C.) was that vision was caused by the interaction of something given out from the eye with something given out by the luminous or illuminated body. He tried to refute the Pythagorean emission theory. In the time of Ptolemy بطليمرس (70-147 A. D.) all these rival theories continued, but he was inclined to the Pythagorean idea and explained reflection and even refraction of light on that supposition. Epicurus ابيقورس and Lucretius لقر اطرس were supporters of what has been termed the quasi-tentacular theory, and imagined that we perceive objects by means of light in much the same way as we feel things by means of a stick.

Curiously enough this strange hypothesis survived for many centuries, until ultimately Alhazen محمد ابن الحسن ابن الهيثم (died in 1038 A. D.) an Arab scientist of Basra, definitely discarded the idea of any emission from the eye and laid down a mathematical theory of light based on the hypothesis that the cause of vision proceeds from the object itself. His conception was that it is not a single ray of light, as had been assumed up to his time, but a cone of rays that proceeds from the object to the eye. On this theory he explained

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reflection and refraction of light. He also examined the anatomy of the eye and showed how with two eyes we see only one object, and also explained many optical illusions. He showed why there was an apparent increase in the diameter of heavenly bodies near the horizon, how distances can be judged by the different vertical angles of the cone of light. This was a great advance in the conception of light and his theory remained accepted in Europe for more than 500 years after him. The Latin translation of his work on Optics was available to Vitellio and Roger Bacon in the thirteenth century.

Even great scientists like Copernicus (1473-1543), Galileo (1564-1642) and Kepler (1571-1630), to whom modern Science owes so much, did not improve upon Alhazen's conception. But Descartes (1638) reverted to the Aristotelian idea of an action of the medium which was called æther. Great strides were made in scientific discoveries, and Romer (1667) established from observations of the eclipses of Jupiters' Satellites that propagation of light had a definite velocity which he measured. Descartes thought that light was due to pressure transmitted instantaneously through a perfectly elastic medium which filled all space, and that colour was the result of some sort of a rotatory motion of the particles of the æther. But it was Charles Huygens (1629-1695) who in 1678 propounded an elaborate wave theory, under which light was due to a mere wave motion in a medium called æther. He gave a complete theory in a definite form, showed how reflection and refraction take place, and accounted for even double refraction. He is unanimously regarded as the true founder of the Wave Theory of light.

Newton (1642-1727), however, remained unconvinced and adhered to the Corpuscular Theory of light, because Huygens' Wave Theory failed to explain satisfactorily the rectilinear propagation of light or the casting of shadows. But simultaneous reflection and refraction at a surface was an apparent difficulty in the way of the Corpuscular Theory. So Newton attributed to the corpuscles "periodic phases or fits of easy reflection and easy transmission," so that sometimes they are in a condition to be reflected and sometimes in a condition to be refracted. He had to assume the existence of the æther, and further that forces of repulsion in the case of reflection and of attraction in the case of refraction come into play. His assumption was that velocity when resolved parallel to surface remained unchanged, but when resolved along the normal was altered. This last assumption resulted in the necessary conclusion that the velocity of light in denser (more refracting) medium must be greater than in rarer (less refracting) one.

The Wave Theory did not replace the Corpuscular Theory till Young (1802) explained how there could be interference on Huygens' Wave Theory, which was not possible on Newton's Corpuscular Theory, and Fresnel (1820) announced how polarisation of light could be explained only on the Wave Theory by assuming that the vibrations in the æther are transverse and not

longitudinal. Both Young and Fresnel demonstrated how an undisturbed succession of waves of sufficient width would move as a beam, spreading out like a shower of particles, without appreciably bending sideways. In this way interference, diffraction and polarisation of light were also satisfactorily explained, for which Newton's Corpuscular Theory was wholly inadequate.

The essential difference between the Corpuscular and the Wave theories is well known. According to the former theory a luminous body continually emits very small corpuscles or particles in all directions. These, when projected from it, bodily travel, like an arrow or bullet, through space with the velocity of light. There is thus a bodily motion of these small corpuscles from one point to another in space, and they carry with them their kinetic energy or energy of motion. According to the latter theory there is an all-pervading medium called æther, the vibrations of which are light. No particle of the æther travels along, but there is a mere relative displacement or disturbance, which is passed on through space. The particles of the æther merely oscillate transversely, and are not at all translated forward longitudinally. The wave propagation resembles the propagation of vibration, when one end of a long steel rod is hit sideways and a vibration is felt at the other end, although in point of fact no particle of the steel rod has travelled from one end to the other.

The Wave Theory of light came to be accepted as a natural theory, because scientists were familiar with the propagation of sound waves and also water waves. Light could be easily imagined to be some sort of a wave, provided an invisible medium like the supposed æther could be invented. By 1850 Foucault and Fizeau established experimentally that the velocity of light in water was less and not greater than that in air. This was a death blow to Newton's Corpuscular Theory, and no option was apparently left but to fall back on the Wave Theory.

But the Wave Theory brought with it its own difficulties :—

(1) The existence of an æther was an indispensable condition, but the nature and properties of the imaginary æther were not easy to formulate. Different æthers had to be postulated for different purposes, as different properties were required to explain different phenomena. The only variety of æther that survived was the *luminous æther* as conceived by Huygens. (2) The first problem was whether this æther should be assumed to be a gas, a fluid or a *solid*. Air and fluids were not found to transmit transverse vibrations, as they offer practically no resistance to distortion. So scientists were compelled to assume that the æther was a *solid* body stretching throughout space. (3) But longitudinal vibrations were not observed at all, as no optical pheno-menon indicated any vibrations normal to the wave front. Accordingly there was no option but to assume that (a) either the longitudinal vibration was

infinite, in which case the æther would be absolutely *incompressible,* or (b) that it was nil or zero, in which case the æther would be *contractile, i.e.,* offering a negative resistance to compression. (4) But as no displacement whatever can take place if the æther were rigid, it had to be assumed that the æther was an *elastic* solid. But it cannot be elastic without having *torsional rigidity, i.e.,* resistance to change of shape. (5) But as there can be no direction fixed in space, the æther must be *uniform* in all directions, and so it must be capable of all possible vibrations; and yet it had *only transverse* and not longitudinal vibrations. If there was a perfect uniformity of the æther inside a crystal, it would not adequately explain polarisation and double refraction. (6) It was found that light had a finite velocity. Mathematically the velocity of a wave propagation in an elastic solid is proportional to the square root of its elasticity divided by its density. So the æther must have (a) either *varying elasticity,* which would destroy its uniformity (b) or *varying density,* which would make it cease to be incompressible, (c) or both, in which case both the difficulties would remain. (7) It was also found that light travels through transparent bodies. So the medium of its propagation must penetrate through such bodies. But if the æther freely pervaded such bodies, then there was no satisfactory explanation why light should have *different velocities* in different bodies. But actually it has. (8) Further, if light is a mere vibration of the æther and the æther penetrates through all bodies and pervades them, there was no reason why most bodies should be *opaque* to light. (9) If the æther were a solid medium, particularly if incompressible, even though elastic, then bodies moving through it ought to experience some resistance, but *no resistance* can be noticed. (10) Again, either the æther inside a body is *affected* by the matter contained in it, or it is not. (a) If it is not, then all bodies ought to be transparent to light as it is a vibration of the æther and not of matter. (b) If it is, then the æther inside the body should be affected in one way only, and the velocities of light of all colours should be the same; but they are not so. (11) Now if the æther were a vast store-house of energy, it might well have a spontaneous motion sometimes, but it has *no spontaneous* motion as a source of light is indispensable. (12) If the æther were an elastic solid, the vibration once produced might well continue, even after the source of light is shut out. But there are no such subsequent *oscillations.* (13) Various other hypotheses were put forward from time to time, *e.g.,* (a) the æther is like an *elastic jelly,* (b) or a *turbulent fluid,* (c) or that matter is like *vortices* or eddies in a stream. (14) None of the apparently contradictory properties of the æther explained *gravitation.* (15) The most insoluble problem, however, was the *æther-drag* or drift of æther. If a material body moves through the ocean of æther, does it carry with itself the æther contained in it, or does it allow the æther to pass through it freely, and so leaves it behind?

The Wave Theory did not remain without another rival. Michael Faraday (about 1833) had conceived of an electrified particle as an octopus-like structure, throwing out tentacles in the form of lines of force forming tubes of force. The tentacles from two such particles somehow took hold of one another and either pulled or pushed one another, causing the forces of attraction or repulsion. Clerk Maxwell (1831-79) developed the idea mathematically and regarded these lines of force as being formed out of electric and magnetic forces. In his hands the properties of the old æther became somewhat transformed, and his electromagnetic field of force had tubes of force having tension and lateral pressure due to electric strain and stress. He regarded the æther around an electrified body as being charged with energy so as to be in a sense polarised. He showed that light was an electromagnetic phenomenon caused by some unknown periodic disturbance in the æther. His remarkable discovery was that the velocity of light was equal to the ratio of any electrical quantity measured in Electromagnetic and Electrostatic units respectively. He laid down a new Electromagnetic Theory of Light. But he could not dispense with the æther, though he gave different properties to it, and his theory also was in essence a Wave Theory. But the classical Wave Theory of light was put to severe experimental tests, and it failed because two different experiments gave exactly opposite results.

Owing to the motion of the earth relatively to a luminous heavenly body, a change called "*aberration*" must occur in the direction in which the waves of light from that body appear to travel, when viewed by an observer on the earth. As the earth revolves round the sun, the direction in which a star is seen would be different in different seasons The stars appear to describe small orbits around their true positions, as a result of the orbital motion of the earth compounded with the velocity of light. But the velocity of light would differ according to the medium through which it passes, and would be reduced if a telescope were filled with water instead of air. In 1871 Airy and Hoek proved by experiment that the aberration of the fixed stars is the same whether the telescope is filled with water or with air. This result could be accounted for mathematically by the assumption that æther waves were *partly* carried along by the moving matter with a velocity reduced in the ratio $(1 - \frac{1}{\mu^2})$ where $\mu$ is the refractive index ; or else the angle of aberration would not be independent of the substance with which the telescope is filled.

On the other hand, in 1887, Michelson and Morley carried out an experiment to test the relative motion of the earth and the æther. If there were any relative motion, then the time taken by a ray of light to pass to and fro along a given distance parallel to the earth's motion would not be the same as that taken by a similar ray travelling over the same distance but perpendicular to

the earth's orbit. These rays can, therefore, be made to have different phases and would cause interference. But not the slightest sign of any displacement of the interference fringes was observable when the apparatus was rotated through an angle of 90°. The only possible conclusion was that the velocity of light is not in the least affected by the motion of the earth, and that therefore the æther in the neighbourhood of the earth did not remain at rest in space but was *wholly* carried along by the earth. Subsequent experiments also, including that of Trouton and Noble, have generally confirmed the same result. (Prof. Jauncey's *Modern Physics*, p. 446.)

In 1893-95 Fitzgerald and Lorentz put forward a hypothesis that the length of the measuring rod itself is altered with the motion of the rod, and that a rod held West to East in the direction of the motion of the earth contracts, and is smaller in length than if the same rod were held North to South at right angles to that motion. However startling the theory of the shortening of the measuring rod may appear, there was no other apparent explanation of the contradictory results obtained by the above experiments.

There was yet another experimental result which destroyed the old Wave Theory of light. The chief characteristic of a wave propagation is its continuity. Theoretically the energy of a radiation for a given temperature should be proportional to the inverse fourth power of the wave length. So with a decrease in the wave length $\lambda$ the energy increases still more rapidly. This equation would give a continuously rising curve. Experimentally, cavity radiation, *i.e.*, black body radiation, which is a perfect kind of radiation as it has all colours, depends on the temperature of the body only and is independent of the material of the cavity. When the cavity radiation, passed through a prism was observed by means of a bolometer, it was found that as wave length decreased, the energy rose up to a maximum, and then fell again with further decrease. It was noticed that the greater the temperature, the more the maximum shifted towards the violet side. Thus the hotter the source, the nearer to the violet side is the concentration, *i.e.*, more violet rays are emerging. The wave length corresponding to the maximum of the curve was represented by Wien's law $\lambda_m T = $ constant, where $\lambda$ is the wave length for the maximum energy and $T$ is the temperature. The old Wave Theory utterly failed to account for the occurrence of the maximum at an intermediate position, which could not occur in a continuously rising curve.

The result that followed is the well-known "violet catastrophy" showing almost an infinite energy for $\lambda$ approaching zero. In the words of Sir James Jeans [*The Mysterious Universe*, p. 32]:

"If light consisted of waves like the waves of the sea, it can be shown that all the light of the analysed sunlight ought to be found at the extreme violet end of the spectrum. Not only so, but extreme violet light waves have an

unlimited capacity for absorbing energy, and as they have their mouths permanently wide open, all the energy of the Universe would rapidly pass into the form of violet or ultra violet radiation travelling through space."

With all these results it might well have been expected that at the end of the nineteenth century, there would be an abandonment of the Wave Theory; but as a particle theory was considered to be an impossible theory there was no help.

In 1900 Professor Planck announced his famous Quantum Theory. According to him the processes of Nature are by jumps or jerks in indivisible quantities. He regarded the process of light absorption as discontinuous. For each wave length there is a definite associated quantity of energy. $E_v = hv$ is the fundamental equation in which $h$ is a universal constant. This means that the size of a unit of energy depends on its frequency; for each frequency there is a distinct unit; and the greater the frequency the greater the energy. This assumption explained the occurrence as well as the shifting to the violet side of the maximum limit of energy with temperature. In 1905 Professor Einstein extended the idea to radiation as well. On this extended theory, a beam of light consists of discreet units, light quanta or photons. Light is propagated in unbroken photons, a fraction of a photon not being seen. Energy is always a complete photon or a multiple of photon, but not a fraction. Now one would have imagined that the conception that energy moves in indivisible quanta would have at once pointed the way to a particle theory. But simply because energy was measured in terms of frequency, and frequency was believed to be incompatible with any particle theory, the tenacious adherence to the Wave Theory continued, but it was coupled with a hypothesis of sudden jumps which would make it almost a particle theory.

The *Photo-electric effect* was another blow to the Wave Theory. If light of a definite frequency be thrown on a metal plate, electrons coming out of it have a sharp maximum velocity. It is found experimentally that (1) the velocity of such electrons is independent of the intensity of the falling light, while (2) the rate of the emission of electrons is proportional to intensity. This means that the velocity does not depend on the intensity at all, but depends on frequency only; the greater the frequency of the incident light, the greater the velocity of the emerging electrons. After this experimental result the Wave Theory again failed, because according to it the intensity ought to have controlled the velocity. But Prof. Einstein's explanation based on Planck's Quantum Theory came to the rescue. If light fell on the plate in quanta, and only one quantum was absorbed by an electron, then its velocity would be the same, so long as light of the same frequency was falling. The increase in intensity would merely increase the number of the electrons that are liberated, and not their velocity. It was assumed that out of the quantum of energy

absorbed, part was utilized in liberating the electron and the remainder gave to it kinetic energy. This explanation also in reality confirmed that light consisted of indivisible particles, as discontinuity is inconceivable in waves.

In 1905 Prof. Einstein first announced his epoch-making Theory of Relativity; the general theory was completed later in 1915-17. It was intended to explain the result obtained by Michelson and Morley, and is based on the assumption that the velocity of light is an absolute constant. Not only is it the utmost maximum possible, but the velocity of light measured by an observer on any moving body relative to himself is always the velocity of light itself, *i.e.*, light seems to him to take the same time to overtake him whether he is moving or is at rest. However fast the observer may be moving, his own velocity as compared to the velocity of light is always zero. As Prof. Jauncey (*loc. cit.*, p. 448) has put it, an observer on the earth, when measuring the velocity of light would find it the same as another observer on a planet moving with a speed half that of light relative to the earth. This is so, although the velocity of light is perfectly definite, *viz.*, $3\cdot10^{10}$ cm. per sec. So far this assumption has worked tolerably well within the Solar System. The theory of Relativity, as propounded by Prof. Einstein and Prof. Minkowski, does not directly touch the conception of light. It would, therefore, be quite out of place to discuss here whether a new interpretation of Relativity based on a different hypothesis is not theoretically possible.

Relativity has no doubt altogether changed the conception of æther. Scientists now avoid that word, and prefer to call it space endowed with certain properties. Some scientists go so far as to regard it merely as a frame of reference, and according to Sir James Jeans (*Mysterious Universe*, pp. 92-93) "it is a creation of thought, not of solid substance"—"a pure abstraction". Prof. C. G. Darwin (*New Conceptions of Matter*, pp. 23-24) considers that the æther has not been completely abolished, but is merely space endowed, among others, with the property of undulation—"it is a true universal carrier", and its business is to carry by its undulations energy placed in its charge. Sir A. S. Eddington (*The Nature of the Physical World*, p. 31) holds that although motion with respect to the universal ocean of æther eludes us and 'velocity through æther' is meaningless, "this does not mean that the æther is abolished. We need an æther. The physical world is not to be analysed into isolated particles of matter or electricity with featureless interspace. We have to attribute as much character to the interspace as to the particles, and in present day physics quite an army of symbols is required to describe what is going on in the interspace.... The æther itself is as much to the fore as ever it was, in our present scheme of the world". Now if the interspace is not a mere void or vacuum, but possesses certain characters, the æther exists,

though we may give to it new properties which our new theories may now require. Indeed, if light is a mere wave motion, there being nothing material which is translated forward from point to point, then unless the whole thing is illusory, there must be some medium which vibrates or else the waves would not be carried along. It is immaterial whether we like to call it æther or space endowed with the property of undulation.

The discovery of the electron by Sir J. J. Thomson during the close of the last century followed by the announcement of the atomic system made by Lord Rutherford in 1911, that it consisted of electrons revolving round a nucleus concentrated as a tiny speck, might well have led on to such a hypothesis of light as one can picture in one's mind. But Professor Niels Bohr's electronic orbits, of definite sizes and shapes, without any intermediate orbits, and representing different levels of energy, put forward in 1913, helped to give to light a mere intangible character. Light was now nothing substantial, but a mere non-material energy, representing the difference of two levels of energy in the electronic orbits. Electrons go whirling round in definite orbits, and every now and then, quite spontaneously, jump suddenly from one orbit to another; this change of orbit implies a difference in levels of energy and this difference is represented by light. As Dr. Whitehead (*Science and the Modern World*, p. 164) has put it:

"The difficulty with the quantum theory is that, on this hypothesis, we have to picture the atom as providing a limited number of definite grooves, which are the sole tracks along which vibration can take place...".

One should have again imagined that the assumption of separate and distinct orbits, without any continuity would have been sufficient to demolish the Wave Theory. But this was still not to be.

Professor Einstein in 1917 carried the hypothesis still further right up to its logical conclusion. Planck's Quantum theory must destroy the Law of Causation itself. Now there was no such thing as cause and effect. There was an apparent capriciousness in Nature. It acted somewhat arbitrarily. One could not predict with certainty which of a number of possible states would follow a particular state. The whole thing was a mere matter of chance or probability, not certainty. The uncertainty is not due to our ignorance, but is natural and inherent. There is an increasing "randomness". On investigating the statistics of the jumps, Professor Einstein found that all could not be caused by heat or radiation, and that some of the jumps must necessarily be altogether spontaneous. Here was another opportunity for abandoning the Wave Theory, and not the Law of Causation. But the theory was too firmly planted in scientists' minds to be so easily dislodged. Still more startling experimental results confirming the particle theory were to follow before it could even be modified.

Experiments had established that (1) an α particle (which is the nucleus of a helium atom) can collide with a hydrogen nucleus, and the two dart off in

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different directions. (2) Similarly an α particle colliding with a helium nucleus has been photographed, and (3) electrons are found to be scattered by atoms. But α and β particles and electrons were then still supposed to be mere particles. In 1923 Professor Compton discovered that X-rays when falling on electrons behave exactly like a swarm of particles, and are scattered as if material particles, moving as separate detached units, collide with electrons and are deflected like billiard balls. The calculation of energy of the photons after the hits verified not only the conservation of energy but also the conservation of momentum. Professor Compton found that the wave length of the scattered photon was lengthened after its collision with an electron, varying with the angle of scattering. The track of an electron, in recoiling from an X-ray, was photographed by means of the cloud produced in a chamber filled with water vapour. If all the conditions of energy and momentum, required by the Law of Dynamics, are satisfied by a photon, one wonders what more is required to prove that light is not a mere wave.

Reference has already been made to the photo-electric effect. The collision of a photon not only with an atom, but also with a molecule, has been established. If the photon of very short wave length, like X-rays, strikes an atom, then the force exerted on the outer electron being comparatively very great, the electron is knocked out and photo-electric effect is produced. On the other hand, those of longer wave lengths do not produce effect to the same extent. In 1928 Sir C. V. Raman observed the scattered light from a mercury arc when passed through a liquid, and found light not only of the same frequency but also of both higher and lower frequencies giving extra lines in the spectrum. Differences in frequencies between such extra lines and the original line corresponded to the frequency of the scattering molecules of the liquid. The result showed that the molecules absorbed just those quanta which had their own frequency, and let through the rest; and further that the effect of the collision of photons with the molecules was either (1) that the photon imparted some of its energy to the molecule, so that the scattered ray was of lower frequency or (2) that the molecule gave a part of its energy to the photon, so that the emerging photon had a higher frequency. This also showed that light behaved as separate units.

As the particle nature is now being denied even to an electron, it is convenient to mention at least one experimental result showing that electrons behave like a swarm of particles. This is *Scintillation*. A scintillating screen is made by lightly powdering a sheet of glass with zinc sulphide crystals. This substance has the property that if one of its crystals is struck by an electron, it gives out a spark, which however is so faint that it can be seen only in a dark room with the help of a magnifying lens. When the prepared screen is exposed to a stream of electrons, scintillations appear irregularly all over it. The behaviour is like that of shower of rain falling on the screen,

each scintillation being caused by a separate drop. The irregular scintillations *prima facie* disprove that there is any wave impinging on the screen.

All the above-mentioned experimental results unmistakably pointed to a particle structure of light and matter. But prejudice in favour of the Wave Theory was over a century old and still remained unshaken. But on any wave theory, waves must of a necessity go on constantly spreading indefinitely. Existence of fossils, which have lain buried in rocks for hundreds of millions of years, becomes utterly inexplicable. By this time they should have evaporated away in waves. But contrary to this classical conception of dispersing more and more, the fundamental fact of regathering of light into $h$-units stares us in the face. Attempts have been made to explain the contradiction by what are characterised as the " Collection-box " theory and " Sweepstake " theory. The first would correctly represent fractions of waves entering an atom in succession, but is admittedly untenable. The second is nothing more than the mere law of chance. Both have had to be used indiscriminately. The hesitating indecision to give exclusive preference either to the classical laws or the quantum laws has been described in an expressive way by Sir William Bragg, who has remarked that " we use the classical theory on Mondays, Wednesdays and Fridays, and the quantum theory on Tuesdays, Thursdays, and Saturdays." Sir A. S. Eddington has felt compelled to feel a little sympathy towards the man whose philosophy of the Universe takes one form on week-days and another form on Sundays. The fact is that in this state of uncertainty both the classical laws and quantum laws, though radically irreconcilable, are applied together. In the words of Sir A. S. Eddington, " the whole procedure is glaringly contradictory but conspicuously successful " (*loc. cit.*, p. 194). Prof. Bridgman's " Operational Viewpoint " now lays down that a concept is utterly meaningless, unless we at the same time describe the operation by which it is measured. It is merely the sum total of the operations used to measure it, and varies with the set of operations. (Jauncey, *loc. cit.*, pp. 534-39).

It must, however, be admitted that there were the two phenomena of interference and diffraction which remained outstanding and apparently proved the Wave Theory of light and made the old Corpuscular Theory an impossible one. Without doubt light can interfere and is also diffracted. The old theory cannot explain how it can do either; but the Wave Theory satisfactorily explains both.

Now although light was regarded as a mere wave motion, protons, electrons, atoms and molecules were considered as definite particles whose motions and positions could be pictured. But electrons were found to be diffracted, and also protons were found to be capable of being diffracted. It was discovered by Messrs. Davisson and Germer that electrons are systematically scattered from a sheet of nickel into certain definite directions, showing the peculiarity that would be due to the diffraction of X-rays by the crystals of

nickel. The closely-packed atoms of a solid body form a pattern and serve the purpose of a diffraction grating. Prof. G. P. Thompson applying the principle of "powder photograph" let a very narrow and straight pencil of electrons moving at a very high speed, fall on an extremely thin metallic film, so thin as to be nearly transparent, and then on to a photographic plate placed beyond the film. The image that was produced consisted of a central spot with circular rings round it, due to the diffraction of the electrons by the small crystals of the metallic film. Recently the diffraction of whole atoms has also been observed. It is not too much to predict that even molecules will soon be diffracted.

Now the position became irreconcilable. Some experiments definitely showed that photons, protons, electrons, and atoms behaved like solid particles, while others indicated that they behaved like waves. They behaved sometimes as particles and sometimes as waves, and there was no general principle yet known which could tell how they would behave. There was some sort of an apparent duality, so that photons, protons, electrons and atoms appeared to be both particles and waves. There remained only two possible courses open. It was like the horns of a dilemma :—

(A) Either not only atoms, electrons and protons, but also light should be regarded as particles and distinct individualities assigned to them. (B) Or one should not only deny individuality to light, but also deny it to protons, electrons and even atoms, and ultimately to molecules also. The conviction against the Corpuscular Theory was so firmly fixed that the choice was made per force of the second alternative.

In 1925 Prof. Heisenberg laid down the foundation of the New Quantum Mechanics or Matrix Mechanics, an entirely mathematical theory, adopting an algebraic method and using matrices, an advanced form of determinants. Prof. De Broglie introduced the idea of waves, though in a rather vague and general way. In 1926 Prof. Schrödinger developed the theory mathematically and applied the method of Differential Equations. In 1928 Prof. Dirac combined Relativity with Quantum Mechanics and laid down Equations known after his name. We have now a perfect system of Wave Mechanics so far as the mathematical aspects are concerned; but it has not even the faintest resemblance to a physical theory.

How the new theory explained interference, the principal cause of the trouble, which according to Prof. Dirac also cannot be explained on any particle theory at all, may be stated in his own words (*Wave Mechanics*, p. 15):

"The answer that quantum mechanics gives to the difficulty (of interference caused by a beam of light when split up into two components of equal intensity) is that one should consider each photon to go partly, into each of the two components, in the way allowed by the idea of the superposition of states. Each photon then interferes only with itself. Interference between two different photons can never occur."

In 1927 Prof. Heisenberg propounded a new Uncertainty Principle or Principle of Indeterminacy that it is wholly uncertain how an electron, for example, will behave. An electron is now supposed to be a train of waves stretching from infinity to infinity; the electron can be assumed to be anywhere in this train, only its speed is known, but its position is unknown. But once any one tries to observe it, the infinite train instantaneously contracts to a zero point, the position becomes known, but the speed becomes indeterminate. A wave group or wave train may have any size or shape; but the position is when known, the speed is indeterminate. A wave group or train must always be moving, it cannot be stationary, its shape also is constantly changing, the number of crests is also changing, generally speaking the number goes on increasing as time passes; the spreading is very rapid if the length of the region is very short, but it is slow in a long train. The train of waves representing an electron goes on spreading from infinity at one end to infinity at the other. But the moment the electron is attempted to be observed, its whole infinite train contract immediately to a zero point. It is supposed to be impossible to know with precision both the velocity and the position at one and the same time.

For an illustration, we may take one of the nearest stars like Sirius, which is fifty-one million million miles away, and from where light travelling at the rate of 186,000 miles per second takes over $8\frac{1}{2}$ years to reach the earth. A quantum of light that starts from it in the form of waves will have spread out almost to immeasurable dimensions by the time it reaches the earth. So long as it has hit nothing, it has gone on expanding continually to an immense extent. But as only a whole quantum, and not any fraction of it, can enter an atom at a time, the result must be that as soon as that quantum in the form of an infinite wave hits an atom on the earth, the infinite train must instantaneously re-gather itself, and contract to almost a zero point; and in this way just one quantum of it enters the atom. The only feasible hypothesis put forward, which is more of an excuse than an explanation, is that only one aspect can be seen in one experiment at a time, and that no experiment has been or can be designed which will show both the particle and the wave aspects at one and the same time.

Prof. C. G. Darwin (pp. 79-80) has suggested an experiment in which a stream of electrons is sent out through two very small holes close together, and then scintillations looked for, which would most probably appear as isolated sparks, but the sparks would all occur in certain bands, and none at all where diffraction theory predicts darkness; but if one hole were stopped, the interference would be destroyed and there would be scintillations everywhere. I submit that in this way both interference bands and scintillation can be seen simultaneously on the same screen. These effects would be easily intelligible on a new particle theory, if light particles emerge

from electrons at fixed intervals corresponding to the periods of their rotations.

According to Sir James Jeans, as radiation, electrons and protons "can appear now as waves and now as particles", they "appear to be particles and waves *at the same time*". He adds, "Clearly we can only preserve our belief in the uniformity of nature by making the supposition that particles and waves are in essence the same thing". (p. 35) At another place (pp. 68-69) he says, "Possibly we may come fairly to the truth if we think of matter and radiation as two kinds of waves—a kind which goes round and round in circles, and a kind which travels in straight lines. This may express the whole difference between matter and radiation, matter being nothing but a sort of congealed radiation travelling at less than its normal speed . . These waves are of two kinds, bottled up waves, which we call matter, and unbottled waves, which we call radiation or light . . . These concepts reduce the whole universe to a world of radiation, potential or existent". "Matter and radiation are found equally to resolve themselves into waves . . . We live in a universe of waves, and nothing but waves."

But just to show what is meant by these waves, I may quote from Sir James Jean's latest book (*The New Background of Science*, pp. 241-42):

"We treat the waves as wave of probability, their extension in space defining the uncertainties of our knowledge. The waves are no longer waves of energy, but of the chance of finding energy . . . So, in the last resort, the waves which we describe as light waves, and those other waves which we interpret as the waves of an electron and a proton, also consist of *knowledge*—Knowledge about photons, electrons and protons respectively."

So unfortunately even these waves are not real waves at all, but purely imaginary and fictitious waves—mere waves of probability. These waves are not now even waves of energy, but only of chance, and so cannot be located in space and time, but are a mere something unthinkable expressed by mathematical equations only. This is the only way in which absurdities like the instantaneous regathering of light is tried to be explained. The waves are a mere mathematical fiction.

Prof. Heisenberg took up the idea that a wave motion can be expressed by means of an infinite Fourier's series, and by suitably selecting the co-efficients any kind of waves can be represented by a process of superposition. In this way a curve would be characterised only by a set of co-efficients in a given order. With a view to secure some stability for an atom and to maintain Prof. Bohr's idea of sudden jumps from orbit to orbit, he used square matrices, an advanced form of determinants, to represent the wave motion. Prof. Einstein's and Prof. Minkowski's continuum had only four dimensions, three of space and one of time. But the Wave Mechanics requires a system of waves of seven dimensions to explain the behaviours of two

electrons, of ten dimensions to explain the behaviours of three electrons, and so on, in fact one plus three times as many dimensions as there may be electrons. The result of this mathematical manipulation is bound to be excellent, because the equations have been deliberately invented by a great mathematical mind to fulfil certain desired conditions; but it involves an abandonment of the commutative laws of multiplication. We had for long supposed that p multiplied by q is equal to q multiplied by p. But now the fundamental equation is that $p \times q - q \times p = \frac{h}{2\pi} \sqrt{-1}$ where $h$ is the Planck's constant. Of course in such an equation p and q cannot be the ordinary arithmetical numbers; they are sets of numbers in certain orders. Sir A. S. Eddington on p. 207 remarks, "All authorities seem to be agreed that at, or nearly at the root of everything in the physical world lies this mystic formula. We do not yet understand that; probably if we could understand it, we should not think it so fundamental."

This basic formula for the modern conception of a light wave is interpreted differently by Prof Born, Prof. Dirac and Prof. Schrödinger. According to Sir A. S. Eddington, "Schrödinger's theory is now enjoying the full tide of popularity, partly because of intrinsic merit, but also, I suspect, partly because it is the one of the three that is simple enough to be misunderstood. . . I do not see the least likelihood that his ideas will survive long in their present form". (pp. 210-11).

Prof. Schrödinger imagines something still more unreal than the æther, *viz.*, a sub-æther as a seat of some sort of oscillations, with beats; but "these beats are not themselves to be identified with light waves, they are in the sub-æther, whereas light waves are in the æther. The beats merely provide the oscillating source which in some way not yet traced sends out light waves of its own period." Sir A. S. Eddington's comment on this conception is "Schrödinger's wave-mechanics is not a physical theory but a dodge—and a very good dodge too. The fact is that the almost universal applicability of this wave-mechanics spoils all chance of our taking it seriously as a physical theory." (p. 219).

Prof. C. G. Darwin's opinion is that "the present theory of the interaction of light with matter is really rather unsatisfactory. The theory, in its final form due to Heisenberg and Pauli, is most extremely difficult; indeed it has been only in the hands of a few of the leading workers in this field that anything has been made of it, and it is, I think, rather widely felt that it is not founded on the right lines." (p. 159).

It is doubtful whether Sir J. J. Thomson really believes in the supposed waves of probability. His latest exposition is a hypothesis of granules moving with tremendous velocity and having a mass almost infinitesimal in comparison with an electron, their resultant attraction or

repulsion being due to the difference in the sense of rotation of vortex filaments.

Now once imaginary quantities like $\sqrt{-1}$ enter into the wave equation, we step out of the real world into an unreal world, and begin to express things by weird ·mathematical formulæ which can neither be pictured nor visualised Physics then becomes a close preserve of the mathematicians, who deal with nothing but mathematical symbols, not capable of any intelligible physical interpretation. Solid matter disappears into something insubstantial, the tangible changes into the intangible, and the real into the imaginary. To quote Sir James Jeans again, "The essential fact is simply that all the pictures which science now draws of nature, and which alone seem capable of according with observational fact, are mathematical pictures. Most scientists would agree they are nothing more than pictures—fictions if you like, if by fiction you mean that science is not yet in contact with ultimate reality;......it is the general recognition that we are not yet in contact with ultimate reality." (p. 111).

It has also been remarked that "the Universe appears to have been designed by a pure mathematician" that "the final truth about a phenomenon resides in the mathematical description of it" and that what we know as light merely "exists in a mathematical formula; this, and nothing else, expresses the ultimate reality." As Dr. Whitehead (p. 143) has put it "Scientific thought is outrunning common sense." The consequences of the assumption that everything in this universe is a mere mathematical equation of an imaginary wave would make the concept a mere structure of pure thought incapable of realisation in any sense which can properly be described as material. In the words of Sir James Jeans, "The universe cannot admit of material representation, and the reason, I think, is that it has become a mere mental concept." "To-day there is a wide measure of agreement, which on the physical side of science approaches almost to unanimity, that the stream of knowledge is heading towards a non-mechanical reality; the universe begins to look more like a great thought than like a great machine. The old dualism of mind and matter . . . seems likely to disappear . . . through substantial matter resolving itself into a creation and manifestation of mind." (p. 137).

The situation cannot be summed up better than in the words of Sir A. S. Eddington, "Nowadays when enthusiasts meet together to discuss theoretical physics the talk sooner or later turns in a certain direction. You leave them conversing on their special problems or the latest discoveries; but return after an hour and it is any odds that they will have reached an all-engrossing topic— the desperate state of their ignorance. This is not a pose. It is not even scientific modesty, because the attitude is often one of native surprise that Nature should have hidden her fundamental secret successfully from such powerful intellects as ours. It is simply that we have turned a corner in the path of

progress and our ignorance stands revealed before us, appalling and insistent. There is something radically wrong with the present fundamental conceptions of physics and we do not see how to set it right." (p. 179).

So this is where the scientists have arrived! And why? Might it not be that over a hundred years ago the initial mistake was made and ever since that time it has been taken for granted that a particle theory of light is an impossible theory, and that, therefore, there is no option but to have a wave theory, howsoever imaginary the waves may be? Might it not possibly be that the rival theories were like the parting of ways, and the choice of the wrong path has led us into an arid desert, into which we have been lured because of the openness of space untrammelled by any obstacles, in preference to the dense and dark forest which had deterred us, but beyond which, if we had pierced through it, lay the beautiful vistas of rich gardens? Might it not be that the greater the progress we are now making at every step towards the imaginary goal, the more we are being drifted away from reality? The imaginary world in which, out of our own choice, we have landed ourselves bristles with greater anomalies than what were sought to be avoided, and is full of apparent absurdities. The present-day physicist's mind is hankering after something real — a new dynamical world, the equations to express which would not involve imaginary factors so as to make it entirely illusory. Mere mathematical formulæ, howsoever perfectly well they may work on paper, cannot satisfy the philosophic mind unless they evolve something comprehensible.

In this desperate state of affairs, a sceptic may be excused if he begins to doubt the very axioms on which the modern conceptions are based: Was Newton right when he conceived that a material body will continue to move for all time to come with the same constant velocity in a straight line so long as it is not disturbed by any force? Was Huygens correct in his belief that in the propagation of light nothing material travels from one point to another but, that there is an imaginary medium which merely vibrates? Were not physicists wrong when they considered an æther indispensable, which all at the same time was solid, elastic, torsionally rigid, incompressible or contractile, uniform in all directions and yet polarised, varying in density, wholly carried along by moving matter when æther is just outside it, but only partially carried along when contained inside the matter? Are we bound to assume that electrons and protons are the ultimate fundamental units of Nature, and that there are no smaller worlds within them? Did Professor Planck propound the truth when he stated that there was a certain arbitrariness in Nature, and that a wave motion can be discontinuous? Must we concur in Professor Einstein's assertion that the Law of Causation does not exist? Is he right in saying that the velocity of light relative to a moving observer is always the same, no matter how fast he is moving? Are we really to believe

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that there is no such thing as force, that there is nothing else in the Universe except relative motion, and that space has higher dimensions, has properties other than mere voidness and is in itself curved? Should we necessarily accept Professor Heisenberg's Principle of Uncertainty and Indeterminacy? Are we compelled to believe with Professors Schrödinger and Dirac that this world is comprised of nothing but mere waves of probability? Is it really the case that the only possible way of understanding physical phenomena is by starting with a unit of time as $\sqrt{-1}$, and by abandoning the laws of multiplication? Have we now no option left but to regard the whole universe as a mere mental concept, and everything around us as nothing but a creation of the mind?

One feels an irresistible temptation to answer these questions by saying that the remarkable degree of perfection attained by the mathematical theories has been at the sacrifice of all philosophical thought, and that the wonderful accuracy of experimental results has been completely' at the expense of simplicity. No doubt a steam roller can most perfectly crush a flea but is it worth while employing such a heavy machinery for the purpose, if the same object can be attained by a much simpler process? Any method of reasoning which reduces the universe into something imaginary cannot furnish a satisfactory explanation of it. Man's instinct, I should think, would rebel against the notion that he is nothing but a system of imaginary waves, and is not a real entity.

Further researches alone will decide whether something simpler and more easy of comprehension cannot be had. As a way out of this impasse, last year, in all humility, I ventured to publish the details of a Rotational Theory of light as a part of a still more general theory, which may surmount the existing anomalies, explain all the known physical phenomena, and bring us back once again into the world of reality. Briefly speaking, that hypothesis is that light consists of material particles (called by me *radions*) which can emerge out of electrons only when their velocity is reduced to a limiting value C. These possess a wave motion in this way that besides their common longitudinal velocity C, and spins round their own axis, they also have different rotational motions corresponding to the revolutions of the electrons in their orbits from which they emerge. The forward motion is measured by the well known velocity of light, and the rotational motions by the periods of time during which they complete one revolution round the axis of their path. Their spin is at present not noticeable. The combined motion is a mere super-position of the three motions. The actual path of a radion is along a helix, a uniform curve round an ellipsoidal cylinder. The motion of a particle in a wave fashion shows both the particle and the wave aspects simultaneously, and reconciles the apparently contradictory experimental results. The formula $\lambda = C.t$ gives us all the results we want. Intensity is measured by the number of

radions per unit area in a cross-section and moving along the path. Reflection is easily explained by the impinging of radions on the atomic systems in a surface, and refraction by their piercing through the inter-spaces. The reflected beam will contain more of the light polarised in a plane parallel to the surface, and the refracted beam more of the light polarised in a plane perpendicular to it. Radions of one definite period will constitute a monochromatic light, in which exactly similar states will recur at intervals of time separated by the period, with the same maxima and minima in between. Permanent differences in phases will cause both interference and diffraction. For such effects, only a periodic motion is required, and nothing more. Molecules, atoms, electrons, protons and radions can all be diffracted. The rotational motions produce transverse vibrations explaining polarisation and double refraction. Radions rotating in planes almost parallel to the grains of a crystal are let through, while those perpendicular to it are stopped. Differences in colour are the result of the different rotational velocities. Decrease of velocity in denser media in which atoms are more closely packed is obvious. So is also pressure of light. Zeeman and Stark effects are explained by the effect of the field on the orbits of rotation, and Compton and Raman effects by the collision of radions with electrons, atoms or molecules. Similar rotational motions of electrons and protons can explain electrification, both negative and positive, and also explain an electric current, and that of emerging radions will explain electromagnetic induction. Electrons and protons will become particles of the same nature, the difference between them being merely rotational velocities, above and below a mean value. The supposed oscillations of electrons and protons are but angular rotations with circumferential velocity respectively less and greater than that of light. The rotational motions of molecules parallel to a fixed direction will explain magnetisation. Further, the constant angular momentum of a radion would explain the un-understood, mysterious "$h$". The constancy of "$h$" is a simple mathematical result of the rotation round an axis, which acts as a virtual central force. It crops up in every experiment because our measuring instrument is light And what is more, Nature need no longer be capricious or proceed by jumps. The sudden jumps from orbit to orbit are a necessary result of successive losses of mass due to the discharge of radions, which must be in multiples of one radion. The interval of time between successive emissions of radions from one atom in one tangential direction corresponds to the period of the revolution of the electron in its orbit. The difference in the losses of momenta caused by emissions on the inner and outer sides of two bodies will explain gravitation. With the restoration of the principle of Continuity, the objective Uncertainty will be removed and the Law of Causation re-enthroned !

Sir James Jeans (p. 69) has suggested that "radiation may ultimately prove to be merely matter moving with the speed of light, and matter to be